WL-TR-8034

PDES APPLICATION PROTOCOL SUITE FOR COMPOSITES (PAS-C) BENEFITS ANALYSIS

South Carolina Research Authority (SCRA)
5900 International Boulevard
North Charleston, SC 29418

January 1997

Final Report for the Period 02 July 1991 - 31 January 1997

MANUFACTURING TECHNOLOGY DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7739

NOTICE

This technical report has been reviewed and is approved for publication.

JOHN BARNES
Project Engineer
Design & Production Methods Branch
Mfg. & Engineering Systems Division

MICHAEL F. HITCHCOCK
Chief
Design & Production Methods Branch
Mfg. & Engineering Systems Division

GERALD SHUMAKER, Chief
Mfg. & Engineering Systems Division
Manufacturing Technology Directorate

REPORT DOCUMENTATION PAGE	FORM APPROVED OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1997	Final 07/02/91 - 01/31/97

4. TITLE AND SUBTITLE

PDES Application Protocol Suite For Composites (PAS-C)

5. FUNDING NUMBERS

C F33615-91-C-5713
PE 78011
PR 3095
TA 06
WU 42

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

South Carolina Research Authority (SCRA)
5300 International Boulevard
North Charleston, SC 29418

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Manufacturing Technology Directorate
Wright Laboratory
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7739
POC: John Barnes, WL/MTIM, 937-255-7371

10. SPONSORING/MONITORING AGENCY REP NUMBER

WL-TR-97-8034

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for Public Release; Distribution is Unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT

This report contains the accomplishments and the benefits analysis of the PDES Application Protocol Suite for Composites (PAS-C) program.

The overall objective of the PAS-C program was to reduce the cost of aircraft composite structural components through the use of concurrent engineering practices enabled by standardized product data information exchange. The program's focus was on standardizing the product information that is exchangedand then developing and demonstrating two of these exchange environments (design to analysis and design to support). The PAS-C team consisted of SCRA, Northrop Grumman, Lockheed Martin, Arthur D. Little and International TechneGroup Inc. Integrated Support Systems, Inc. provided key support to the PAS-C program demonstration. Boeing was a major contributor during the initial program tasks including requirements identification and capture.

14. SUBJECT TERMS

Product Data, Automation, Reprocurement, Integration, ALC.

15. NUMBER OF PAGES

131

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASS OF THIS PAGE.	19. SECURITY CLASS OF ABSTRACT	20. LIMITATION ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z239-18
298-102

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AAM	Application Activity Model
ACSP	Aircraft Composite Structural Part
ADL	Arthur D. Little, Inc.
AIM	Application Interpreted Model
ALC	Air Logistics Center
AP	Application Protocol
ARM	Application Reference Model
AS	Application Protocol Suite
ATMCS	Advanced Tooling Manufacture for Composite Structures Program
ATS	Abstract Test Suite
BOM	Bill of Materials
BREP	Boundary Representation
CAD	Computer Aided Design
CAD	Commercial Aircraft Division
CADAM	Computer Aided Design And Manufacture
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAX	CAD/CAM/CAE
CBA	Cost Benefit Analysis
CD	Committee Draft
CLS	Contractor Logistic Support
COTS	Commercial Off The Shelf
CSL	Contoured Skin Laminate
CSP	Core Stiffened Panel
D&T	Dimensioning & Tolerancing
DBMS	Data Base Management System
DED	Data Element Description
DFAR	Defense Federal Acquisition Regulation
DIS	Draft International Standard
DL	Data List
DoD	Department of Defense
DoE	Department of Energy
DPD	Digital Product Definition Data
DPM	Digital Product Models
EDCARS	Engineering Data Computer Assisted Retrieval System
EDMICS	Engineering Data Management Information and Control System
FAR	Federal Acquisition Regulation
FCIM	Flexible Computer Integrated Manufacturing
FDIS	Final Draft International Standard
FEA	Finite Element Analysis
FW/BB	Framework/Building-Block
GOSET	Operational Group for the Standard for Exchange and Transfer
HoQ	House of Quality
HTML	HyperText Markup Language

IDL	Indentured Data List
IGES	Initial Graphics Exchange Specification
IL	Index Lists
IPO	IGES/PDES Organization
IRB	Industry Review Board
IS	International Standard
ISO	International Organization for Standardization
ITI-OH	International TechneGroup Incorporated - Ohio
JEDMICS	Joint Engineering Data Management Information and Control System
JSF	Joint Strike Fighter
LCC	Life-Cycle Cost
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Record
ManTech	Manufacturing Technology
MSC	MacNeal Schwendler Company
NC	Numerical Control
NCAD	Northrop Computer Aided Design
NCAL	Northrop Computer Aided Lofting
PAS-C	PDES Application Protocol Suite for Composites
PD	Product Data
PDD	Product Definition Data
PDES	Product Data Exchange using STEP
PDM	Product Data Management
PDS	Product Data Set
PL	Parts List
PTD	Provisioning Technical Data
RAMP	Rapid Acquisition of Manufactured Parts
SC4	Subcommittee 4
SDAI	Standard Data Access Interface
SOTA	State-of-the-Art
SPARES	Spare Parts Production and Reprocurement Support
STEP	Standard for the Exchange of Product Model Data
TC184	Technical Committee 184
TCA	"T" Composite Assembly
TDP	Technical Data Package
UGII	Unigraphics System II
VIG	Vendor Implementation Group
WG	Working Group

This page intentionally left blank.

EXECUTIVE SUMMARY

The overall objective of the PDES Application Protocol Suite for Composites (PAS-C) program was to reduce the cost of aircraft composite structural components through the use of concurrent engineering practices. These practices would be enabled by standardized product data information exchange. The program's focus was on standardizing the product information that is exchanged and then developing and demonstrating two of these exchange environments (design to analysis and design to support). The PAS-C team consisted of SCRA, Northrop Grumman, Lockheed Martin, Arthur D. Little and International TechneGroup Incorporated. Integrated Support Systems, Inc. provided key support to the PAS-C Program demonstration. Boeing was a major contributor during the initial program tasks including requirements identification and capture.

The results of PAS-C will allow for the efficient exchange and storage of composite part information among life-cycle stages. The life-cycle stages addressed were Analysis, Design, and Support. The PAS-C Program developed these data exchange standards utilizing ISO 10303 [the International Organization for Standardization (ISO) product data information standard STEP (STandard for the Exchange of Product model data)]. The standardized product information that is exchanged within these environments are Application Protocols (APs) within STEP.

Significant accomplishments

- Established clear and comprehensive composite part information requirements
- Ensured these part information needs can be satisfied using STEP
- Identified and prioritized potential benefits from utilizing this part information in a standard information exchange environment
- Developed an ISO application protocol for Composite and Metallic Structural Analysis and Related Design (AP 209)
- Demonstrated the capabilities of AP 209 as part of other program initiatives
- Developed a draft version of an ISO application protocol for Technical Data Packaging Core Information and Exchange (AP 232) which satisfies both commercial and DoD requirements for submission to the ISO for qualification as a Committee Draft document
- Identified and documented requirements for an application protocol for the Exchange of Product Definition Data from Design Engineering to Manufacturing Engineering for Composite Structures (AP 222)
- Generated test criteria that will aid in validating implementation of the Application Protocols
- Developed demonstration software
- Conducted and supported pilots and demonstrations of AP 209 and AP 232 that will lead to near term implementations

The PAS-C program engaged software and hardware vendor support while refining implementation scenarios and identifying potential marketing opportunities for vendors. The PAS-C AP Suite Demonstration was conducted in November, 1996.

The PAS-C Cost/Benefits Analysis (CBA) was approached from a Life Cycle Cost (LCC) perspective. This was primarily due to the nature of the problem and the long term benefits that could be obtained from the use of the technology developed under the PAS-C Program. **Figure 1** delineates the approach that was used in the LCC Analysis. The shaded areas represent the LCC tasks related to the PAS-C Program, while the upper portion of the figure represents the PAS-C technical development efforts. Phase I of the PAS-C Program evaluated the current State-of-the Art (SOTA) for PDES/STEP, the aerospace composite structural part information requirements, and the areas where the most benefits could be obtained from utilization of this technology. From this analysis, a preliminary CBA was documented. The Phase II technical effort to develop the STEP application protocols was driven by the need to satisfy the information requirements and payback areas identified in the preliminary LCC Analysis. Phase III of the PAS-C Program as initially defined consisted of the program demonstration and a final report and cost/benefit analysis.

Due to the phased approach that the PAS-C Team employed to develop the three Application Protocols, the APs are at different levels of approval in the ISO standards process. The **Design to Analysis AP, AP 209 - Composite and Metallic Structural Analysis and Related Design**, pertains to data that link design, finite element and detail structural analysis applications. AP 209 has passed the Committee Draft (CD) ballot within ISO and has several venders that have supported preliminary implementations of the AP and commenced development of commercial products. Initial projections for labor savings for AP 209 were 25% for tasks related to *Detail Aircraft Composite Structural Part (ACSP) Analysis* and 10% for tasks related to *Preparation of Aircraft Composite Structural Part Models and Drawings*. **The savings from the user feedback range from 11-48%.** This range can be attributed to several factors. The leading factor is the ability of the Aircraft Composite Structural Part analyst to be able to perform more advanced analysis (e.g., using solid FEA models directly from the original design solid model) which was not practical in 1990.

AS-IS	AS-IS	AS-IS
- IDEF0	- Validate IDEF0	- Validated IDEF0
- Information Requirements	- Validate Information Requirements	- Validated Information Requirements
- Data Utilization Percentages	- Validate Data Utilization	- Validated Data Utilization
- Part Costs	- New Cost Data	- Final Cost Data
TO-BE	TO-BE	TO-BE
- Improvement Opportunities	- Validate Improvement Opportunities	- Demonstrated Improvements
- Activity Scenarios	- Refine Activity Scenarios	- Recommended Activity Scenarios
<u>Preliminary LCC Analysis</u>	<u>Refine LCC Analysis</u>	<u>Final LCC Analysis</u>
Phase I →	Phase II →	Phase III

Figure 1 PAS-C Cost/Benefits Analysis using Life Cycle Cost Approach

The **Design to Support AP, AP 232 - Technical Data Packaging Core Information and Exchange**, defines the structure to package/relate groups of product information so that configuration controlled exchanges can be achieved among Product Data Management (PDM) systems. The emphasis is on information that is typically utilized for representing design disclosure of an item. The AP has a complete AAM, an ARM that has undergone extensive National and International review, an initial Application Interpreted Model (AIM) that has been reviewed by ISO and PDES, Inc. personnel, and an initial set of Conformance Classes for utilization. AP 232 has been submitted to the ISO qualification committee for review and processing as a Committee Draft ballot. The ARM has been populated for testing and the PAS-C demonstration implemented a core subset of the Data Definition Exchange Conformance Class. The PAS-C demonstration was conducted with software developed by the PAS-C Team for internal systems and by Commercial vendors for Commercial Off The Shelf (COTS) products. Several areas have been identified where AP 232 could be implemented to enable a shift in the processes that industry utilizes to manage data. Savings projections for this AP have not yet been quantitatively identified because of the paradigm shift that industry is undergoing in managing their data with Product Data Management Systems.

The **Design to Manufacturing AP, AP 222 - Design Engineering to Manufacturing Engineering for Composite Structures**, will extend the initial concepts for a 'Drawingless Engineering Design Representation' that are contained in AP 203 (Configuration Controlled Design). The information and concepts contained in this AP require a continuing paradigm shift in how Industry manages and documents the design of the product: from *Engineering Drawings* to *Part Representations* (primarily 3-D for mechanical parts). Due to the early stages of development of this AP, there are no vendor implementations at this point in time. This AP has an Application Activity Model (AAM) that is complete and a preliminary Application Reference Model (ARM). The initial projections for labor savings were 10% for tasks in *Manufacturing Pre-Planning*, 5% for tasks in *Manufacturing Detail Planning*, and 12% for tasks in *Provide Tools*. The *Provide Tools* task includes NC Programming tasks (38% labor savings) and Tool Design tasks (27% labor savings) related to ACSPs.

The **PAS-C demonstration results confirmed that AP 209 and AP 232 will perform their designed function**. In addition, the demonstration showed that the two APs are compatible with each other and are an integrated suite of Application Protocols. Their functionality was demonstrated between a prime contractor and a subcontractor. These interfaces demonstrated compatibility across the heterogeneous environments which exist within and between companies. A significant goal of PAS-C was to identify and spur development of systems and capabilities which can be utilized in the industry. The demonstrations clearly indicated opportunities where vendor products can be utilized to aid the functions within the scope of the Application Protocol Suite. Vendor products which were available to the program at the time of the demonstrations were included in the demonstrations and their commercial availability highlighted.

Industry has embraced the technology developed under the PAS-C Program. PDES, Inc., an industry/government consortium representing companies with over $600 billion in annual revenues, has committed to take AP 209 and AP 232 to the next step in the international standards community, and PDES, Inc. member companies have begun pilots using the PAS-C technology. Commercial software vendors have also begun developing products which incorporate the technology.

Overall, the PAS-C Program has been a true team effort between industry and government and is considered by many to be a hugh success. Clearly, the PAS-C developed technology is being adopted by industry which will result in significant benefits far into the future.

1 INTRODUCTION

This report contains the accomplishments and the benefits analysis of the PDES Application Protocol Suite for Composites (PAS-C) Program.

The overall objective of the PDES Application Protocol Suite for Composites (PAS-C) program was to reduce the cost of aircraft composite structural components through the use of concurrent engineering practices enabled by standardized product data information exchange. The program's focus was on standardizing the product information that is exchanged and then developing and demonstrating two of these exchange environments (design to analysis and design to support). The PAS-C team consisted of SCRA, Northrop Grumman, Lockheed Martin, Arthur D. Little and International TechneGroup Incorporated. Integrated Support Systems, Inc. provided key support to the PAS-C Program demonstration. Boeing was a major contributor during the initial program tasks including requirements identification and capture.

Phase I, the Needs Analysis, consisted of a set of tasks aimed at:

- Establishing clear and comprehensive composite part informational requirements,
- Ensuring these part informational needs can be satisfied using STEP,
- Identifying and prioritizing potential benefits from utilizing this part information in a standard information exchange environment, and
- Generating a plan for the development and demonstration of the integrated Application Protocols (APs).

During Phase II, Application Protocol Development, two APs which complied with the ISO STEP documentation requirements for Committee Draft APs and one application reference model (ARM) for a STEP compatible AP were developed by the PAS-C Program. The first AP, Composite and Metallic Structural Analysis and Related Design (AP 209), was submitted to the ISO as a Committee Draft and was sent for international balloting by the ISO in February, 1996. This ballot completed in August, 1996, which resulted in the AP being approved for advancement to ISO Draft International Standard. Work was also completed on the Application Reference Model (ARM) for the original AP2, Design to Manufacturing (ISO Part number AP 222). AP3, originally designated as Design to Support, and now known as the Technical Data Packaging Core Information and Exchange (TDP) Application Protocol (AP 232) was developed for submission as an ISO Committee Draft document for balloting in the international community. **Figure 2** shows the life-cycle overview flow of information elements for the three application protocols utilizing their international designation numbers AP 209, AP 232, and AP 222.

Additional Phase II activities included:

- Obtained industry consensus on the scope of AP 232, while completing the initial version of the AP document for submission to ISO qualification.
- Developed the Application Reference Model for AP 222.
- Created comprehensive models, depicting the interrelationships of the information being exchanged within the Application Protocols, and
- Generated test criteria that will aid in validating implementation of Application Protocol 232.

In Phase III, demonstration software was developed and pilots and demonstrations of AP 209 and AP 232 were supported. A real production scenario using AP 209 and AP 232 together served as the PAS-C Program demonstration scenario. Composite part information was shared among various CAD/CAE and PDM systems across corporate enterprises simulating a structural redesign of an aircraft's horizontal stabilizer. Additionally, software developed under the PAS-C Program was used in other government and industry consortia AP 209 pilot projects.

The PAS-C Program organization is shown in **Figure 3**. SCRA led the program team from Lockheed Martin, Northrop Grumman, Arthur D. Little (ADL), and International TechneGroup Incorporated (ITI). ISS provided key support during the demonstration phase. Boeing was a significant contributor during Phase I of the program.

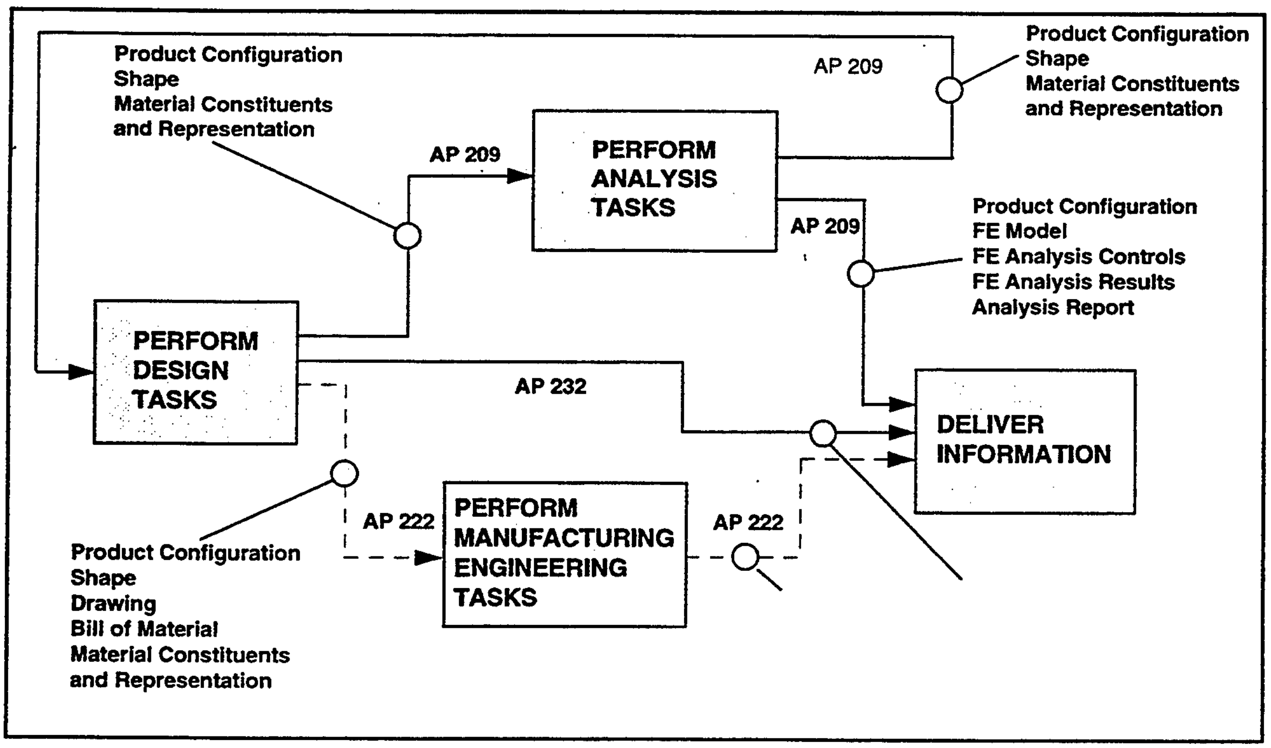

Figure 2 Life-Cycle Overview Flow of Information Elements

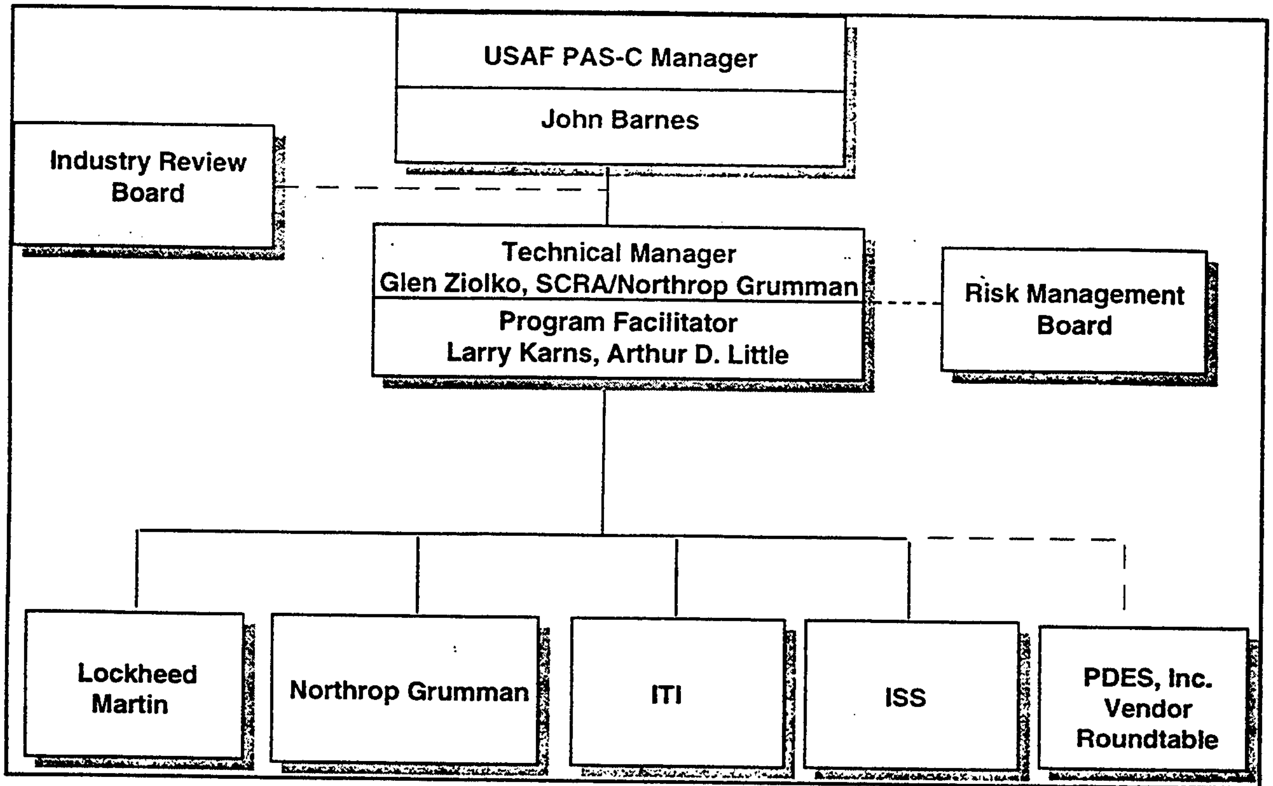

Figure 3 PAS-C Program Organization

The Industry Review Board (IRB) was an important part of the PAS-C Program. The IRB provided a forum for the program team, the Air Force, other Government agencies, U.S. industry, and the PDES community to review the progress of this effort and to offer guidance. The program team was also aided by a Risk Management Board, made up of senior executives from the participating companies.

The PAS-C Team worked in a distributed environment. By working at their own facilities, the PAS-C staff expedited the technology transfer the Air Force desired. In addition to heavy usage of Internet capabilities, team members were linked via high speed modems into the International Center for Product Data Technology located at SCRA and the National PDES Testbed at NIST. They used electronic bulletin boards to facilitate transfer of major documents and models and conducted frequent staff meetings using a teleconferencing network. The Air Force was also a part of this distributed environment.

This page intentionally left blank.

2 ACCOMPLISHMENTS

The PAS-C Program consisted of three phases:

- Phase I - Needs Analysis for Application Protocol Suite
- Phase II - Develop the Product Data Application Protocol Suite
- Phase III - Demonstration of the Application Protocol Suite

The overall PAS-C Program roadmap is shown in **Figure 4**. This section identifies specific accomplishments of the PAS-C program.

2.1 Phase I (Needs Analysis) Accomplishments

Phase I commenced in July, 1991, and focused on establishing the functional views of the composite product life-cycle and identifying information requirements.

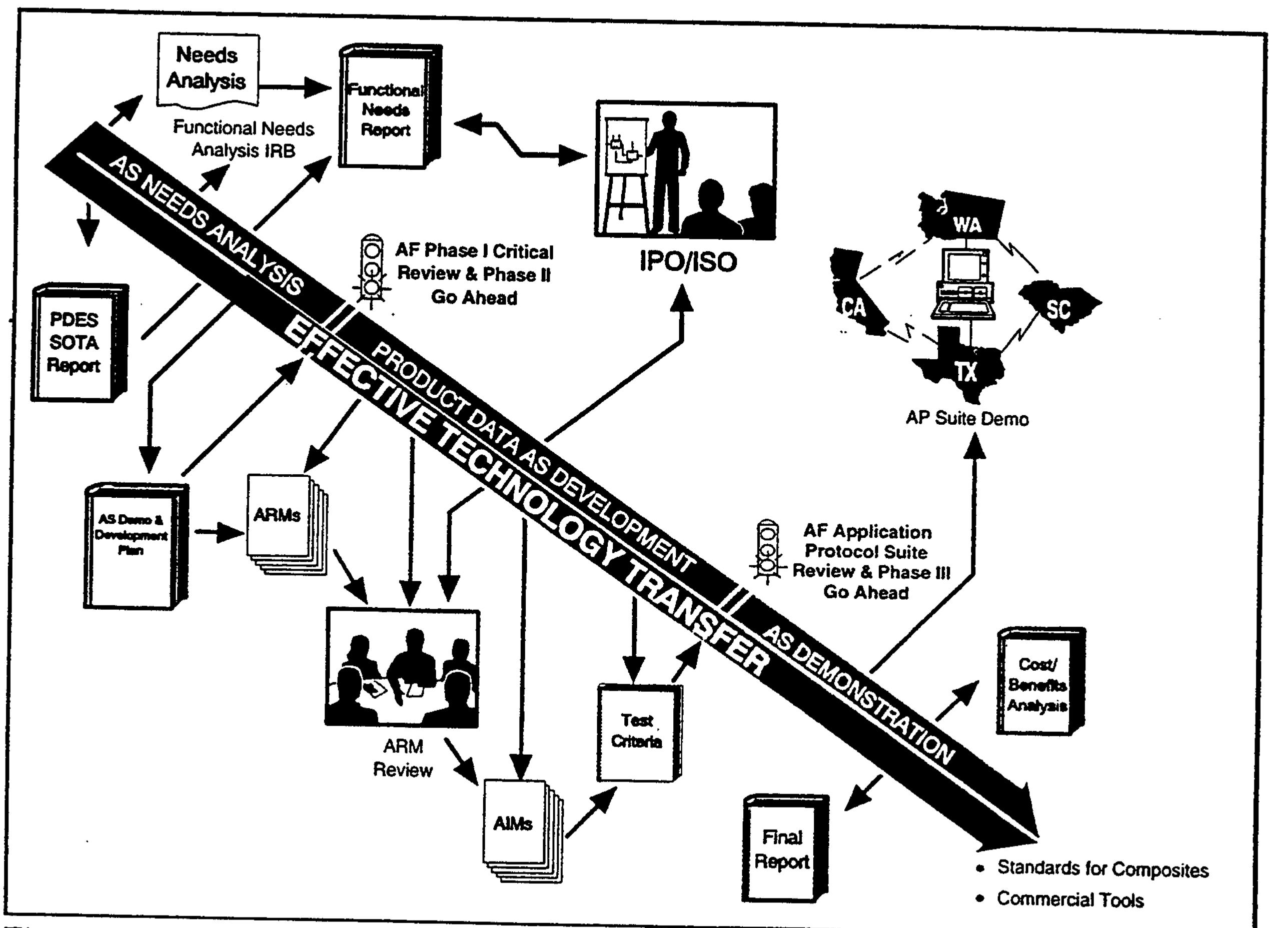

Figure 4 - PAS-C Program Roadmap

2.1.1 Identified Needs

A large portion of the PAS-C team's effort during Phase I was spent on identifying composite part information needs. The needs gathering process consisted of:

- Selecting a set of part families to establish scope,
- Standardizing composite constituents terminology,
- Capturing informational characteristics per functional view,
- Identifying a comprehensive set of life-cycle activities unique to composites, and
- Constructing an extensive IDEF0 model tying the informational needs to their functional requirements.

The results of the part family selection are shown in **Figure 5**, **Figure 6**, and **Figure 7**.

The three part families, Contoured Skin Laminate, Core Stiffened Panel, and "T" Composite Assembly are the prominent composite part types. They are made up of the majority of basic constituents that all other structural parts consist of; thus, indirectly cover a larger spectrum of composite parts than just the three shown. The program deliverable *Functional Needs Report for the PAS-C Program* [1] contains the analysis for part family selection and example part selection. The program deliverable *PAS-C Sample Part Set* [2] identified three example parts which were candidates to be used in the Demonstration Phase (Phase III) and contained the actual released part drawings. Subsequent to this recommendation, the decision was made to use an actual part which was being redesigned from metallic to composite material. This part is shown in **Figure 8**.

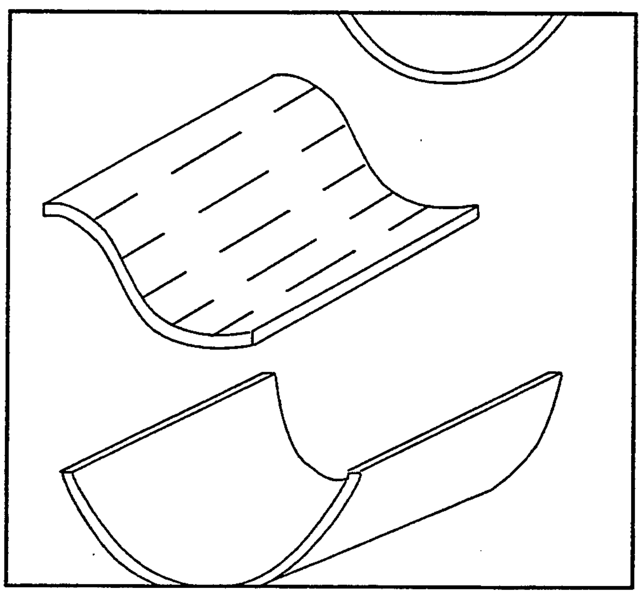

Figure 5- Contoured Skin Laminate (CSL) - Ply Laminate General

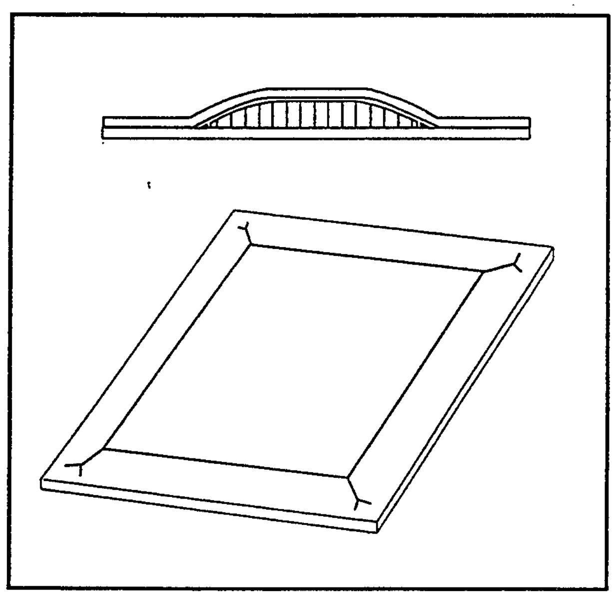

Figure 6 - Core Stiffened Panel (CSP) -Composite Layup/Assembly - Stiffened Panel (Core)

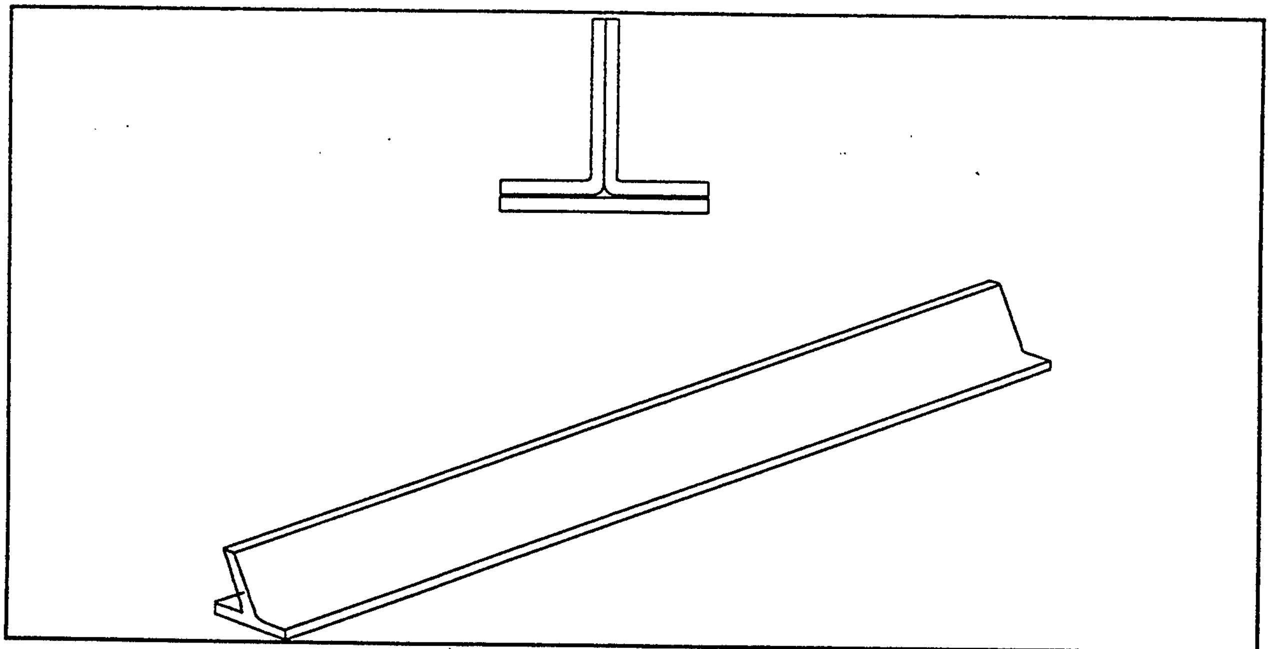

Figure 7 - "T" - Composite Assembly (TCA) Composite Layup/Assembly - "T" Section

As an aid in standardizing and organizing composite part information, some standard terminology had to be established. This terminology consisted of standard descriptions for the components that make up any composite part and functional view descriptions. **Figure 9** shows these standard composite components as composite items and gives examples. This list of composite items in

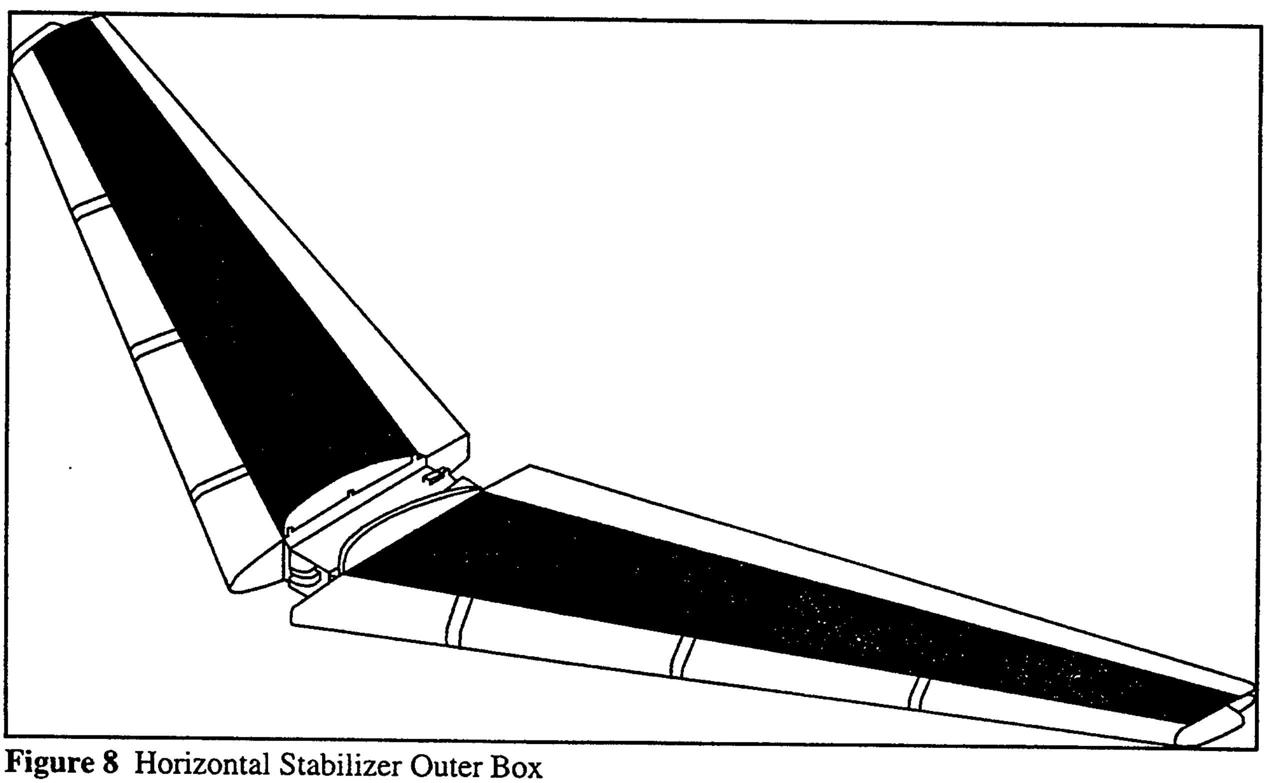

Figure 8 Horizontal Stabilizer Outer Box

Figure 9 represents physical constituents that can stand on their own during at least one stage in the creation of a composite part.

Figure 10 shows how these composite items and the functional views were used to decompose and organize composite part information over its life-cycle stages. This structure is what PAS-C refers to as the Framework/Building-Block (FW/BB) method. FW/BB is a comprehensive methodology for capturing characteristics about a specific composite item from multiple functional views.

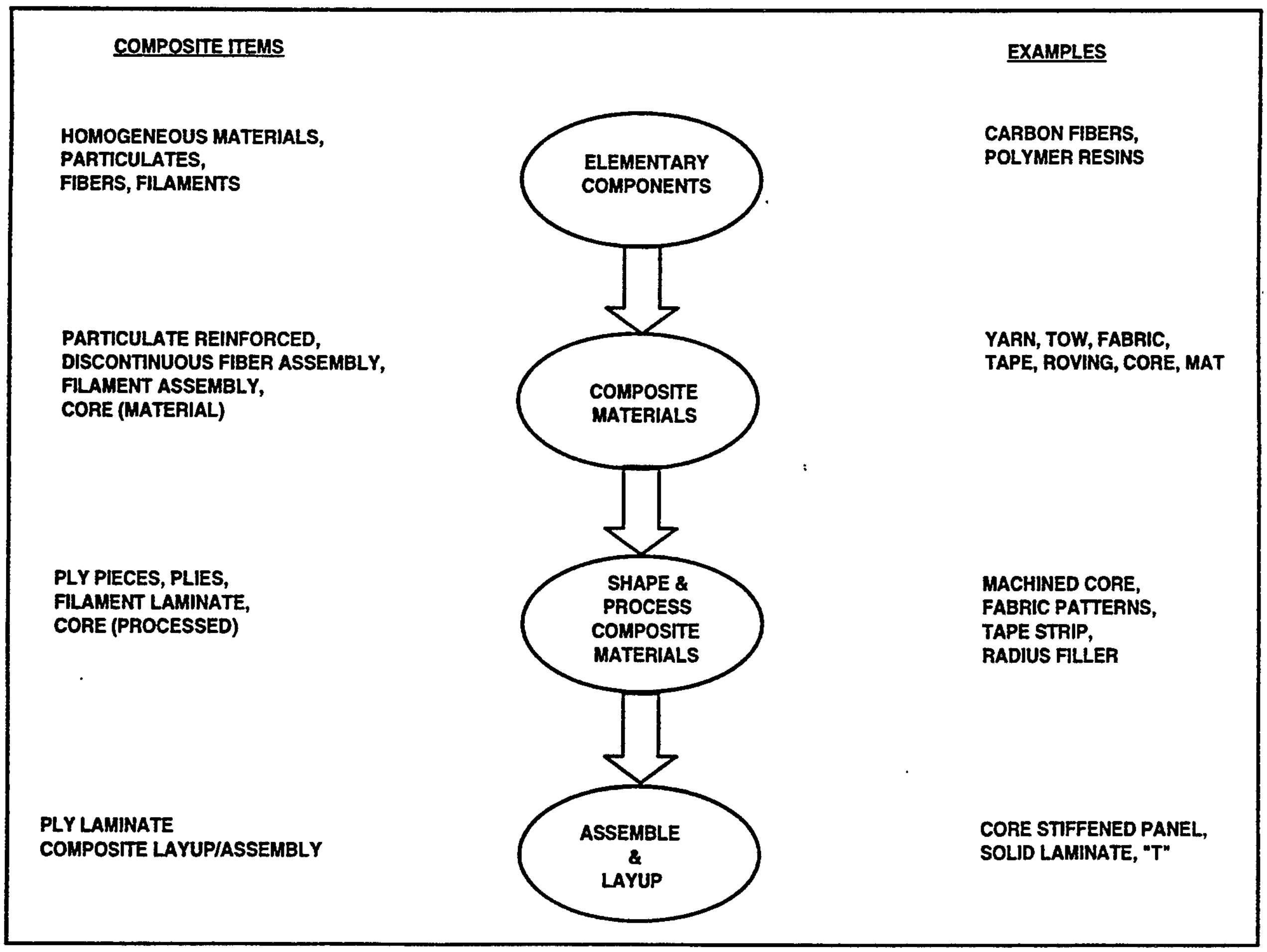

Figure 9 - Composite Item Relationships

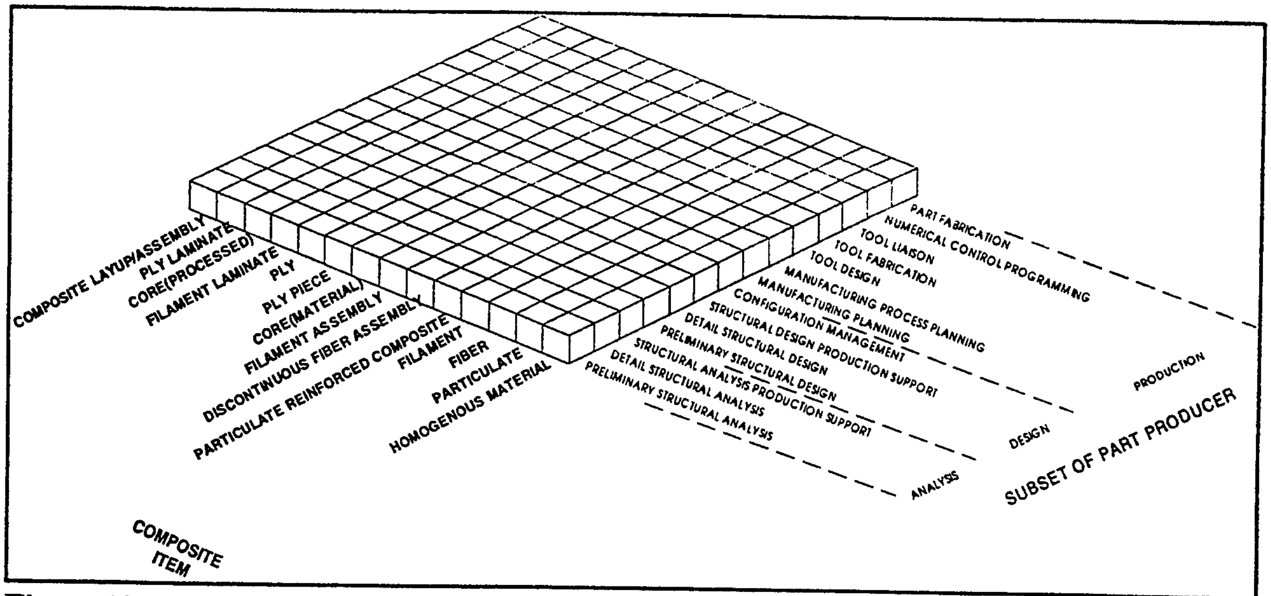

Figure 10 - Composite Product Item Suite Information Organizational Structure

Capturing the information in this generic manner allows for this knowledge to be reused by other projects. The results of utilizing this methodology for composites and the documentation of terminology used can be found in *Functional Needs IDEF0 Activity and Information Models for the PAS-C Program* [3].

An extensive activity model was developed for composites covering the areas of product analysis, design, and manufacturing. Additional detail descriptions for each of the three part families were created by decomposing the activity model further in the areas where specialized activities existed. This information model was created and reviewed by composite experts in three of the most prominent composite aircraft component manufacturers in the world: Northrop Grumman, Lockheed Martin, and Boeing. This model was the basis for tying the product information back to its real functional needs. This model was also used as the cornerstone for creating the specific Application Activity Model (AAM) for each of the APs within PAS-C. Activity node tree diagrams and their definitions were also included with the IDEF0 model in reference [3].

2.1.2 PDES State-of-the-Art Assessment

A State-of-the-Art (SOTA) Assessment of PDES (Product Data Exchange using STEP) was accomplished in Phase I. The assessment was restricted to those areas that could impact the achievement of the PAS-C goal of developing an Application Protocol Suite (AS) for composite parts. The assessment covered the STEP baseline documents shown in **Table I** . This Table depicts the likelihood of which documents applied directly to PAS-C and the date of the document that was evaluated.

Table I - PDES State-Of-The-Art Assessment Sources

Part No.	STEP Part Title / Related Document Title	Applies to PAS-C	Base-lined
1 *	Overview and Fundamental Principles	Yes	Oct 91
11 *	EXPRESS Language	Yes	Apr 91
21 *	Clear Text Encoding of the Exchange Structure	Yes	Mar 91
31 *	Conformance Testing Methodology and Framework: General Concepts	Yes	Jan 91
41 *	Fundamentals of Product Description and Support	Yes	Oct 91
42 *	Geometric and Topological Representation	Yes	Jun 91
43 *	Representation Structures	Yes	Jul 91
44 *	Product Structure Configuration	Yes	Aug 91
45	Materials	Yes	Dec 90
46 *	Visual Presentation	Yes	Oct 91
47	Shape Tolerances	Yes	Dec 90
48	Form Features Information Model	Maybe	Aug 90
101 *	Draughting Resources	Yes	Aug 91
104	Finite Element Analysis	Yes	Oct 91
201 *	Explicit Draughting	Maybe	Oct 91
202	Associative Draughting	Maybe	Oct 91
203 *	Configuration Controlled Design	Maybe	Sep 91
204	Mechanical Design using Brep	Maybe	Oct 91
205	Mechanical Design using Surface Representation	Maybe	Oct 91

Each document represents a Part in STEP. A Part is one portion of the Standard and is assigned to a particular class within the Standard. These classes are:

- Overview,
- Description Methods,
- Implementation Forms,
- Conformance Testing,
- Integrated Resources, and
- Application Protocols.

Each Part was evaluated based upon maturity, content, stability, and adherence to ISO methods. A brief summary of each Part was also provided as an introduction to that Part's assessment. An overview of the relevant standards organizations and the processes that must be completed to make an AP for PAS-C was also created as part of the assessment. The PAS-C document that contains this assessment is the *PDES State-of-the-Art Assessment for the PAS-C Program* [4].

The research that went into formulating this document provided valuable knowledge in determining a doable scope for PAS-C.

2.1.3 Functional Needs to PDES SOTA Comparison

A comparison of the identified functional needs to PDES/STEP capabilities and contents was performed in Phase I. The Quality Function Deployment (QFD) House of Quality (HoQ) methodology was used to correlate the information needs to available PDES/STEP resources. Voids in the STEP Part resources where needs were not met were identified. A cost to fill each void was estimated. Then the needs were prioritized with respect to both benefits to the PAS-C Program objectives and to cost.

The results concluded that all but a few of the voids found during the comparison were not judged to be serious. It was recommended that the majority of the identified voids be addressed by the PAS-C Application Protocol Suite, with the remainder to be addressed by liaison with the PDES/STEP effort to enhance the PDES/STEP information model resources.

Based upon the comparison of PAS-C composite informational needs to PDES/STEP resources, it appeared that the IPO/ISO addressed the more critical areas of information. The analysis indicated that there were no critical voids within PDES/STEP that would adversely alter PAS-C goals. It was concluded that the risk of relying on PDES/STEP development processes and resources would be manageable.

2.1.4 Scope and Benefits

Phase I, the Needs Analysis, consisted of a set of tasks aimed at establishing clear composite part information requirements. These informational requirements were prioritized based on potential benefits from utilizing PAS-C's demonstration part information in a standard information exchange environment. These potential benefits were derived by composite experts from their respective functional disciplines of Analysis, Design, Manufacturing and Support. Using the IDEF0 model from the Identified Needs task (as described previously) potential benefits were estimated by the experts.

Figure 11 graphically represents the groupings of the various information exchange environments evaluated. Each of the circled areas shows one of the major exchanges and clearly depicts the overlap between the exchanges. Appearing on the diagram are the following high level information exchanges and a reference back to the IDEF0 diagrams ID's that appeared in reference [3]:

- 1.0 - Design to Analysis (diagram ID - A223)
- 1.1 - Internal for Analysis (diagram ID - A2233)
- 2.0 - Design to Manufacturing (diagram ID - A2)
- 2.1 - Internal for Manufacturing (diagram ID - A23)
- 3.0 - Design to Support (diagram ID - A0)
- 3.1 - Internal for Design (diagram ID - A2232)

Based on these benefits, the three Application Protocols within the Suite (Design to Analysis, Design to Manufacturing, and Design to Support) were scoped. These APs only address a portion of the total life cycle of a composite part's information exchange. However, the PAS-C team established that this was the most significant portion that could be standardized. Focusing on exchanges from the design function allowed PAS-C to capture the core exchange information. One of the Designer's primary tasks is to put the information of a composite part into a general format that any other functional area can extract. Today this is done through a drawing. The APs PAS-C created not only allow the information about the part to be extracted visually but also allow for intelligent applications to directly access the captured part knowledge.

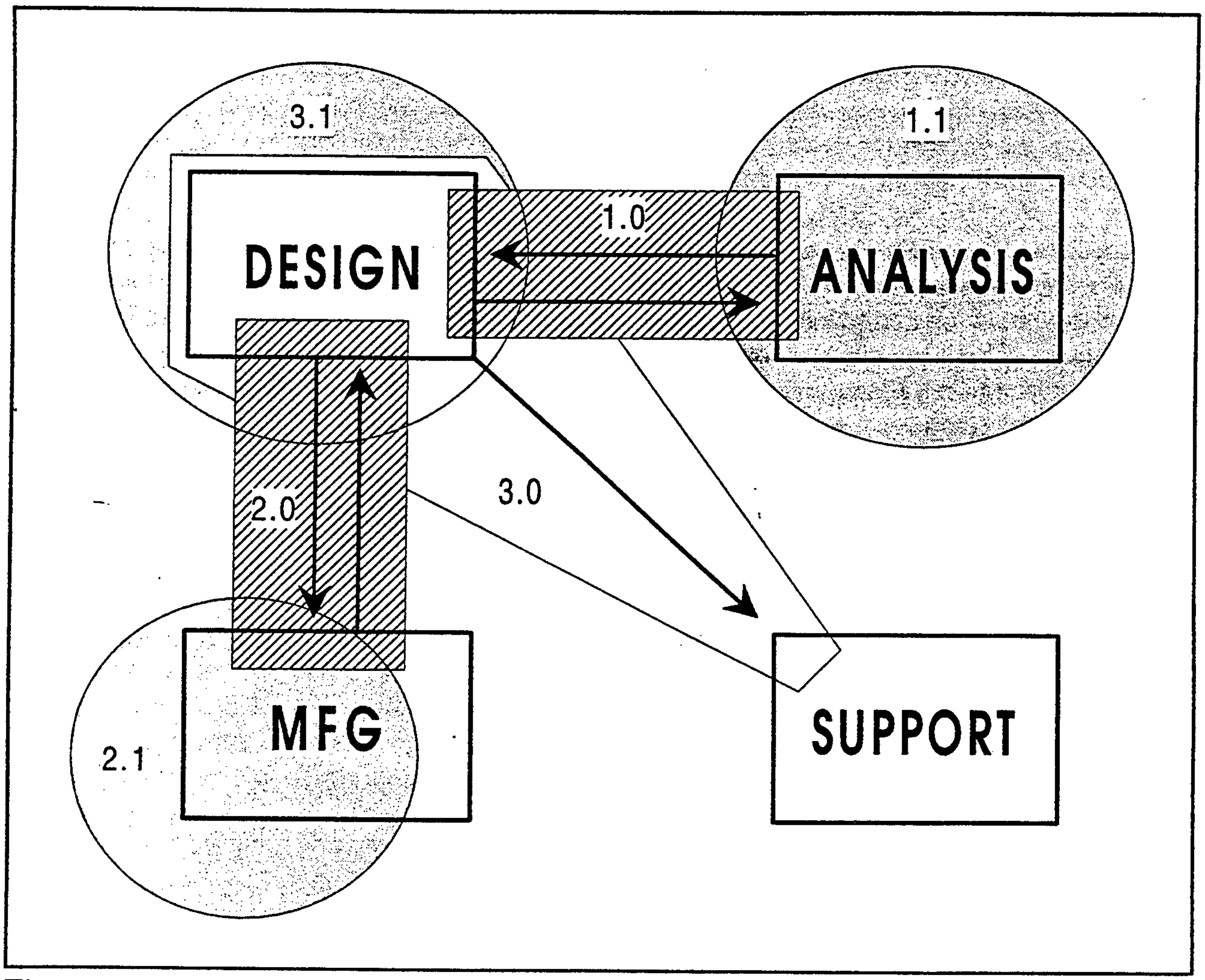

Figure 11 - AP Data Exchange Scopes

Table II shows the results of the preliminary activity cost analysis when applied to the three original PAS-C demonstration parts. These results were formulated by running each demonstration part through the activity cost analysis evaluating each of the application protocols (Design to Analysis, Design to Manufacturing, and Design to Support). The values in **Table II** reflect the summation of the activity cost analysis results for each of the three application protocols when only their highest payback data exchange scenario was considered. The three demonstration parts are a Contoured Skin Laminate (CSL), Core Stiffened Panel (CSP), and "T"-Composite Assembly (TCA). The value represents labor hours to perform the life-cycle tasks. **Table II** shows the hours it takes today (AS-IS) to perform the tasks and the hours it is estimated to take when the application protocols are implemented (TO-BE).

Table II - PAS-C AP Suite Implementation Preliminary Activity Cost

DEMO PART	PAS-C AP SUITE IMPLEMENTATION			
	AS-IS	TO-BE	Δ HOURS	REDUCTION
CSL	2184	1811	373	17%
CSP	4401	3623	778	18%
TCA	660	556	104	16%

These three Application Protocols showed the highest payback with the criteria that the PAS-C Program has developed. The activity cost analysis that was run against the demonstration parts did not account for many of the cost items that are very hard to quantify such as: better configuration control, fewer paper requirements, reduction/elimination of lost data, and schedule reduction. Even though these very hard to quantify cost items were not accounted for, the calculated benefit for implementing the PAS-C AP Suite could have been over 1200 hours for the original PAS-C demonstration parts. Detail descriptions of the AP scopes and supporting benefits activity cost analysis data can be found in the documents *Scoping and Benefits Criteria (Volume I - Executive Summary and Overview) for the PAS-C Program* [5] and *Scoping and Benefits Criteria (Volume II) for the PAS-C Program* [6].

2.1.5 Development Plans

A major accomplishment of the PAS-C Program was to formulate and initiate a comprehensive and detailed plan for developing an integrated set of STEP APs. The plan not only included the basic AP creation tasks such as AAM, ARM, AIM, and test purposes, but also the consensus building tasks such as international expert reviews and STEP qualification/ integration workshops. This development plan integrated both the Air Force and ISO requirements and deliverables into a challenging schedule.

The basic components of an AP and associated Abstract Test Suite are shown in **Figure 12**. The order in which these components are developed is important because each builds off the previous one. The development order of the components are:

- Scope/Requirements & Commonalities (AAM)
- Application Reference Model (ARM)
- Application Interpreted Model (AIM)
- Conformance Requirements & Test Purposes
- Abstract Test Suite

In building an integrated suite of APs, the first component was very critical. To insure that the APs were integrated, extra effort in identifying commonalities in scope was essential. The PAS-C team accomplished this by identifying common characteristics of standard composite part components from the perspective of different functional/discipline views. These common characteristics formed the basis for a common information model that was developed in Phase II. Abstract Test Suite development was not included under the PAS-C contract.

2.2 Phase II (Application Protocol Suite Development) Accomplishments

Phase II commenced in July, 1992. The Application Protocol Suite (AS) development was based on the scope established in Phase I, the Needs Analysis, as well as requirements subsequently refined for the Technical Data Package (TDP) project. From this scope, a development plan was developed to use PAS-C resources in an effective manner to meet the identified needs.

The AP development process was an evolving process which was being refined by the ISO Technical Committee 184 (Industrial Data and Global Manufacturing Programming Languages). This process

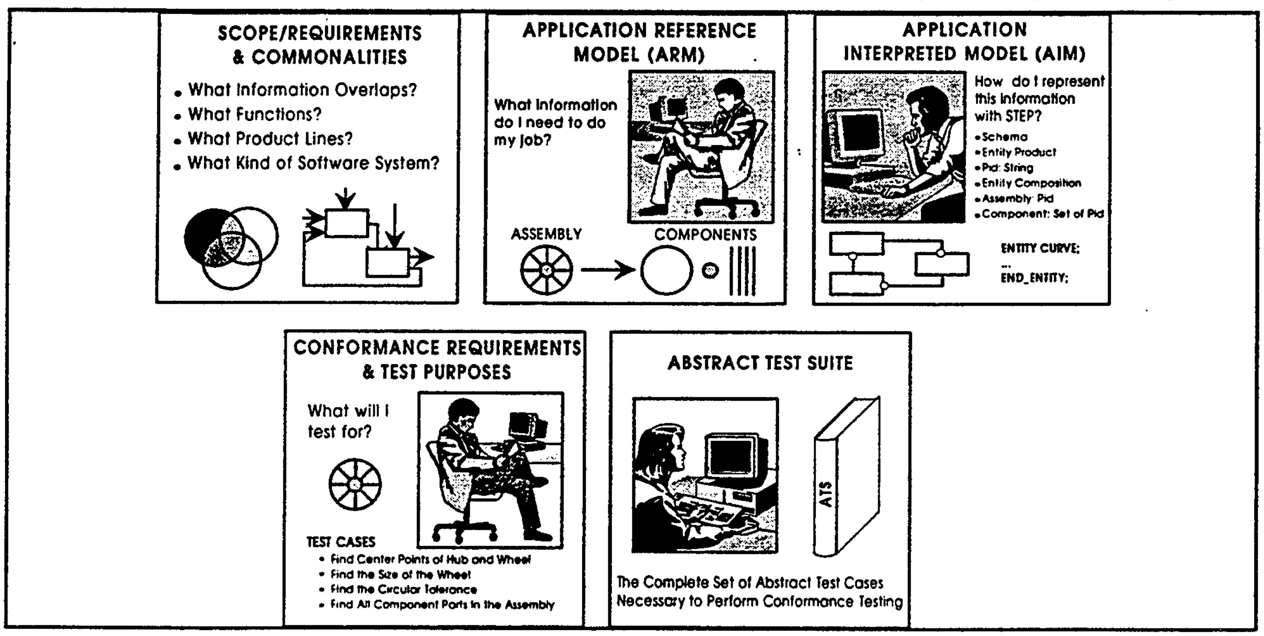

Figure 12 - Components of an AP and Associated Abstract Test Suite

has evolved considerably since the PAS-C project was initiated. In particular, the process now has requirements for significant work to be done in AP integration and review. This process is under the control of the various Committees and working groups within ISO. Accordingly the development of the APs into an Application Protocol Suite as performed by the PAS-C Program was modified as the program progressed.

During Phase II, Application Protocol Development, two APs which complied with the ISO STEP documentation requirements for Committee Draft APs and one application reference model (ARM) for a STEP compatible AP were developed by the PAS-C Program. The first AP, Composite and Metallic Structural Analysis and Related Design (AP 209), was submitted to the ISO as a Committee Draft and was sent for international balloting by the ISO in February, 1996. This ballot completed in August, 1996, and resulted in the AP being approved for advancement to ISO Draft International Standard. Work was also completed on the Application Reference Model (ARM) for the original AP2, Design to Manufacturing (ISO Part number AP 222). AP3, originally designated as Design to Support, and now known as the Technical Data Packaging Core Information and Exchange (TDP) Application Protocol (AP 232) was developed for submission as an ISO Committee Draft document for balloting in the international community.

The PAS-C Program used a structured technical approach for developing an Application Protocol Suite (AS) for composites. This Framework/Building-Block (FW/BB) methodology was designed to address the integratibility, extensibility and nesting of Application Protocols (APs). The building blocks shown in **Figure 13** can be reused on multiple APs.

The approach used in conducting the PAS-C Program was designed to maximize the consensus within the communities (composites, standards, software applications and government) with regard to the following PAS-C products: Composite Needs Analysis, PDES State-of-the-Art (SOTA) Assessment, PDES Voids, AS Development Strategies, AS Test and Demonstration Criteria, Application Reference Models (ARMs) and Application Interpreted Models (AIMs). Achieving a consensus in these areas was an important aspect of the program. The results of the Needs Analysis tasks performed in Phase I formed the basis for developing the Application Protocol Suite.

2.2.1 Development Approach

This AS Development Approach was based on the *Guidelines for the Development and Approval of STEP Application Protocols* [7] as published by ISO TC184/SC4/WG4. The major steps in AP Development are Application Activity Modeling, Application Reference Modeling, Application Interpreted Modeling, and Test Criteria. The Application Activity Model (AAM) was based on the activity modeling performed in the Phase I Needs Analysis and documented in reference [3]. With the definition of AP scope as defined in reference [6], the Activities and ICOM's for each scope were documented in an AAM. The AAM effort resulted in completion of an AP Summary Sheet for

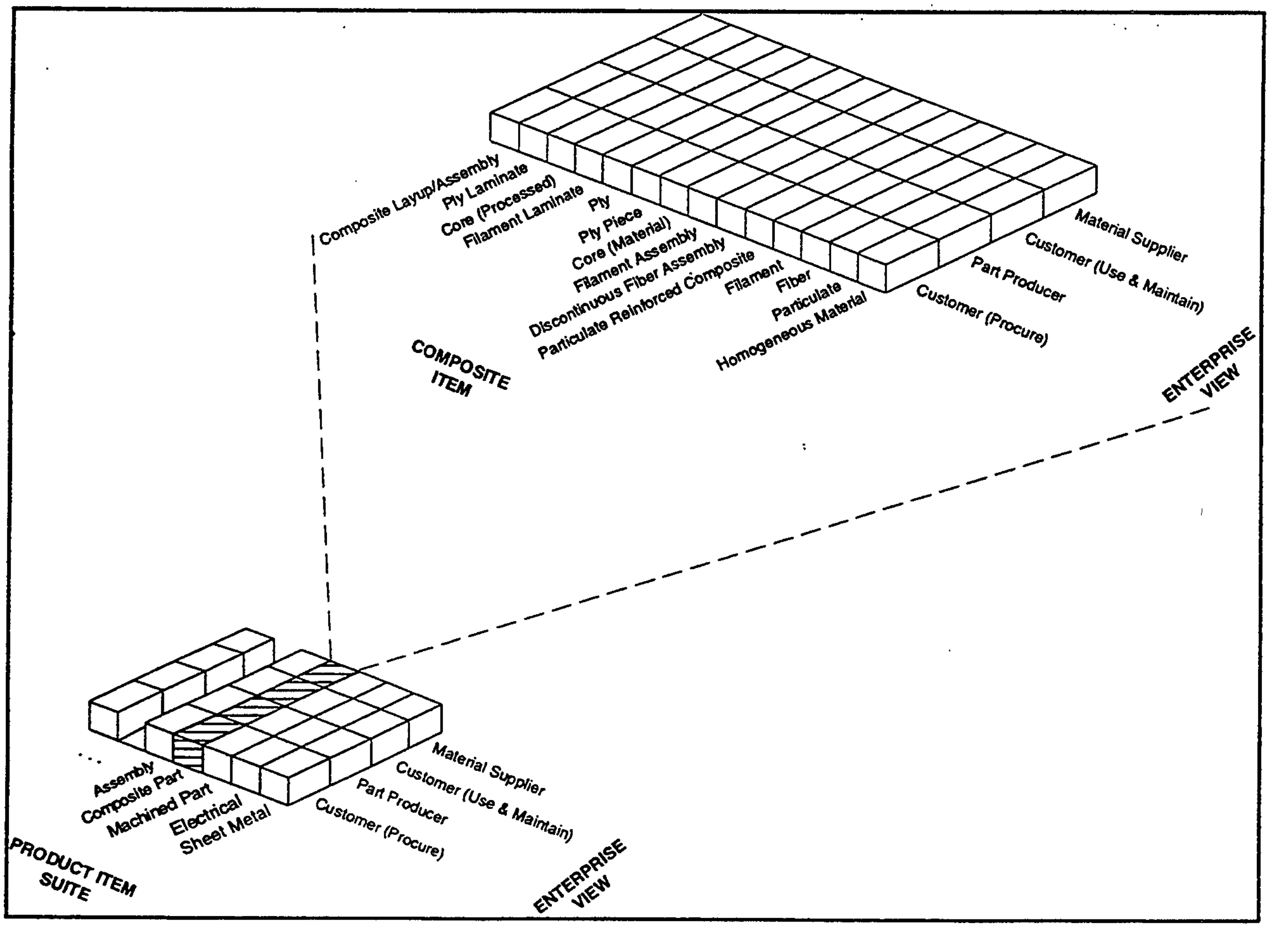

Figure 13 - Framework/Building-Block Structure for Composites Application Protocol Suite

IPO/ISO distribution. The Application Reference Model (ARM) is the definition of the information model in terms of the application expert. This can be viewed as the definition of the application requirements without regard to STEP Resource capabilities. The guidelines document allows definition of this model in IDEF1X, NIAM, or EXPRESS. The team capabilities made IDEF1X and EXPRESS the preferred choices. Developing in EXPRESS [8] had the advantages of being simpler, better known to the modeling team, and closer related to the follow on work of Application Interpreted Model (AIM) Development. IDEF1X had the advantages of being in existence longer with a more developed methodology but had the real disadvantage of being closely tied to relational databases. The team developed the ARM in EXPRESS with a graphical representation in EXPRESS-G. The ARM was validated by testing and domain expert review. Interpreting the ARM in terms of the STEP resources was accomplished in AIM development. The extensive knowledge of the STEP resources which the PAS-C team possessed was utilized in this effort. Another major part of this was coordination with the ISO Integration Committee. The Test Criteria Development was the last major effort. The goal was to provide criteria which formed the basis for measuring whether a future implementation would meet the AP's requirements and would therefore be able to interface with other applications supported by the AP.

2.2.2 Development Tasks

This section describes the tasks that were necessary in developing a STEP Application Protocol (AP). The tasks are divided into major categories. The first category, Develop the Common Application Protocol Suite Components is a specific task for the PAS-C Program. The creation of a suite of Application Protocols that will share some of the same data requires additional scoping over that for a single AP. This shared data must be identified and modeled so that all of the APs can utilize it for their own specific applications. Other major categories correspond to the main components of an AP and include the Application Reference Model (ARM), the Application Interpreted Model (AIM), and the AP Test Criteria.

These tasks and sub-tasks with the exception of Develop the Common AS Task are based on the *Guidelines for the Development and Approval of STEP Application Protocols* [7] and the Qualification Manual, as published by WG4. The sub-tasks that have a deliverable number and an * associated with them are the tasks that were required for a deliverable by the PAS-C contract.

2.2.2.1 Develop the Common Application Protocol Suite Components

- Build AS Planning Model - This consisted of further refining each APs overlap in functionality and informational needs. The deliverable was a set of informational constructs that defined the common (applicable to more than one AP) set of the AS. These constructs were presented in a Planning Model.
- Build Common AS Information Model - The common informational constructs were used to build EXPRESS-G and EXPRESS with definitions for this model. A first pass was performed at determining a minimum set of information constructs that needed to be instantiated in order to minimize manual knowledge transfer. (A

standard query path within the common AS Information Model.)

2.2.2.2 Develop the Application Protocol Suite Scope and Content

- Documented the Requirements for Product Data Communication and Potential APs.
- Identified the correspondence of Requirements to the Scope and Architecture of STEP (with the assistance of STEP experts).
-* Completed and refined the AP Scope and Requirements for each AP {CDRL A017 - Application Reference Model}.
-* Created the IDEF0 model and associated glossaries for the activities within the refined scope to describe the use of the product data within the application domain {CDRL A017}.
- Submitted the candidate AP summary to the SC4 PMAG for approval of a new AP project.
- Participated in a Qualifications planning meeting.
- Created the example parts and usage scenarios.
- Provided expert reviews for fitness testing and evaluations.
- Defined AP Development & Validation Plan.
- Created a Scope and Requirements Evaluation Report which included Issue Logs, list of expert reviewers with their qualifications and summaries of the reviews {CDRL A017}.

2.2.2.3 Develop the Application Reference Model (ARM)

-* Defined the ARM EXPRESS data model {CDRL A017}.
-* Developed the ARM construct definitions (entities, attributes and relationships within a Unit of Functionality (UOF) {CDRL A017}.
-* Developed the ARM construct assertions (the relationships spanning UOFs) {CDRL A017}.
-* Developed the list of UOFs to include the definitions of the UOFs and the functions that they support {CDRL A017}.
- Submitted the ARM to WG4 AIM development project.
- Submitted the ARM to WG4 for the AIC library integration work session.
- Developed the ARM usage tests of concepts in the AP.
- Performed ARM validation using expert modelers and application experts.
- Resolved the ARM issues.
- Created the ARM Validation Report which summarized the ARM validation test plan, included the validation results, provided a rationale for selection of the representative usage tests and usage scenarios, and an analysis of the degree of coverage provided by the validation testing.
-* Submitted the ARM Documentation Package {CDRL A017}.
- Created and submitted Group 1 documentation to WG4 for qualification.
-* Perform Air Force review of the ARM {CDRL A017}.

2.2.2.4 Develop the Application Interpreted Model (AIM)

-* Developed and documented the ARM to AIM mapping by interpreting the integrated resources constructs and the AIC library and summarized the rationale with which the AIM was derived from the ARM {CDRL A018 - Information Model}.
-* Interpreted the integrated resources constructs and the AIC library with the help of the WG4/ADP, WG4/APIP and WG4 Resource model integration groups.
-* Developed and documented new constructs to support the APs as necessary and submitted them as candidates for inclusion in existing STEP Parts or the creation of new STEP Parts for composites {CDRL A018- Information Model}.
- Validated the AIM by ensuring that the usage tests developed for the ARM are supported by the AIM.
-* Reviewed with the IPO. Conducted a meeting with the IPO to review potential integrated resources shortcomings (both entity and methodological) and any additional information constructs developed {CDRL A018}.
- Resolved AIM issues as time and resources permitted.
-* Produced the AIM (EXPRESS (Long form and Short form) & EXPRESS-G) with the assistance of WG4/ADP {CDRL A019 - Application Interpreted Model}.
-* Submitted the AIM Information Model {CDRL A018}.
-* Compiled the AIM Long Form (& Short Form) {CDRL A019}.
- Developed the AP usage guide which described the way the AP is to be used.
- Developed the AIM validation report which summarized the AIM validation test plan and the results, including the rationale for the selection of the test purposes, usage tests, usage scenarios and the issues log.
-* Submitted the AIM EXPRESS {CDRL A019}.

2.2.2.5 Develop the AP Test Criteria

-* Defined the conformance requirements, test group structure and test purposes with the assistance of WG6 {CDRL A020 - Test Criteria}.
-* Developed the Test purposes from the test groups and the Conformance Requirements and Test Purposes Evaluation Report {CDRL A020}.
- Submitted Group 2 documents to WG4/QP for initial qualification approval.
- Prepared the PICs Proforma - defined explicitly the implementation flexibility, if any, allowed by the application protocol specification.
- Prepared the implementation specific requirements.
- Completed the AP documentation.

2.2.3 Refined Application Protocol (AP) Scopes in Suite

A portion of the PAS-C's team effort was applied to refining the scope of each application protocol within the Suite. The three application protocols (APs) are:

- Composite and Metallic Structural Analysis and Related Design (AP 209)
- Exchange of Product Definition Data from Design Engineering to Manufacturing Engineering for Composite Structures (AP 222)
- Technical Data Packaging Core Information and Exchange (AP 232).

2.2.3.1 Composite and Metallic Structural Analysis and Related Design (AP 209)

The goal of this AP is to link Design, Finite Element and Detail Structural Analysis applications in a manner that provides a bi-directional information exchange capability.

This AP addresses: (1) the transfer of geometry (point, line, curve, and surface) information between Design and Analysis applications primarily relying heavily on work from other existing STEP APs, as appropriate; (2) specialized composite data such as contiguous ply boundaries, ply stacking sequence and ply fiber orientation angle(s); and, (3) finite element (FE) mesh, loads, and boundary conditions, analysis controls, and a common analysis output data format for FE and detail (such as panel buckling or joints) linear static structural and thermo-structural analyses.

The analysis of metallic structures is within scope since homogeneous metallic material response is a subset of anisotropic composite material response. The material response description and the lack of specialized composite information are the only major differences between composite and metallic structural analyses.

2.2.3.2 Exchange of Product Definition Data from Design Engineering to Manufacturing Engineering for Composite Structures (AP 222)

The goal of this AP is to link Design Engineering to Manufacturing Engineering for composite structural parts. Design engineering is that part of design which produces the details of the individual part design. Manufacturing engineering tasks are those that are above the shop floor which convert the design product definition into shop floor production capability. This includes project manufacturing planning, process planning, tool design, and NC programming. Also applicable portions of the product definition which is exchanged within applications of design and manufacturing engineering are in scope.

This AP will address the transfer of product definition of a composite structural part which is currently represented in engineering drawings, parts lists, application lists, and CAD datasets. Included is the shape defined in 3-D geometry, configuration control information, as well as definition of specialized composite data such as ply boundaries, ply stacking sequence, ply fiber orientation, and core stiffener definitions.

Composite structural parts made up of polymer matrix reinforced with high strength fibers are in scope. Typical fabrication involves assembling pre-pregs followed by a cure cycle. Information about most piece parts built of layers or assembled sections is handled, however.

The scope excludes information which is furnished to shop floor manufacturing such as NC programs or complete work instructions. Documentation generated in manufacturing, such as inspection and as-built documentation, is also excluded.

2.2.3.3 Technical Data Packaging Core Information and Exchange (AP 232)

This application protocol provides the structure to package/relate groups of product information so that configuration controlled exchanges can be achieved among Product Data Management (PDM) systems. The emphasis is on the information that is typically utilized for representing design disclosure of an item. Requirements for design disclosure are satisfied for both commercial and government views. The goal of this application protocol is to provide a migration path from document based management of product data to a product based management view.

Design disclosure is engineering definition sufficiently complete to enable a competent manufacturer to produce and maintain quality control of item(s) to the degree that physical and performance characteristics interchangeable with those of the original design are obtained without resorting to additional product design effort, additional design data, or recourse to the original design activity. Design disclosure information is typically manifested in the form of drawings, associated lists, documents, and product data sets.

A major developmental effort in this AP was in representing the information and functional requirements for lists that are associated with drawings and/or product data sets. The associated lists include Parts Lists, Data Lists, Index Lists and Indentured Data Lists. The AP also represents exchange requirements for commercial and government industrial requirements related to product data management and exchange.

The intent of AP 232 is to integrate the functionality of AP 201, AP 202, and AP 203 in a manner whereby industry can interoperate with current drawing-based industry practices or product-based industry practices.

The data that has been used for validation of this AP consists of aircraft composite structural parts such as a core stiffened panel, contoured skin laminate, and a T composite assembly. Additional technical data was provided by the Navy RAMP Program for mechanical piece parts and assemblies. Also, sample data was provided by Northrop Grumman and Lockheed Martin for the validation process.

The functional requirements for this Application Protocol have been derived from requirements defined in the Needs Analysis of the PDES Application Protocol Suite for Composites (PAS-C) Program, ANSI Y14 series of standards, MIL-T-31000 (General Specification for Technical Data

Packages), the Computer-Aided Acquisition and Logistic Support (CALS) Product Definition Data (PDD) Current Environment Report, the Sacramento Air Logistics Center's Depot Support Requirements Document, the NIST/CALS Requirements Document for the Technical Data Package (TDP) and the Requirements Document Addendum (30 September 1994) and the F-22 Program during the Digital Product Models Program. International requirements have also been provided.

The PAS-C Program developed AP 232 in conjunction with CALS, NIST and PDES, Inc. **Figure 14** reflects the approach used to develop AP 232 which fulfills the AP3 requirements and the initial TDP requirements. This approach provided for maximum leveraging of government and industry resources while also addressing commercial and DoD requirements.

AP 232 was developed using a rapid prototyping scenario. In general, rapid prototyping of user requirements, system designs and product concepts is a practical way to ensure key requirements and functionality are addressed. By populating this AP with user supplied data, the AP developers, users and implementors focused on the data requirements and their realization in the resulting AIM. Historically, significant data modeling efforts are made in the STEP AP development process prior to conducting pilot implementations. An AP can reach Committee Draft and even Draft International Standard (DIS) status before any serious pilot implementations are conducted. The further an AP progresses through the standardization process, the more difficult it is to make technical changes. The approach taken on AP 232 should minimize "technical change" problems by utilizing the rapid prototype concept.

2.2.4 Application Protocol Suite Integration

The application protocol suite integration strategy was based upon an orderly logical methodology from the initial PAS-C requirements gathering aspects through the development of the application protocols themselves. This strategy was based upon the Framework/Building-Block (FW/BB) methodology described earlier.

2.3 Phase III (Application Protocol Suite Demonstration) Accomplishments

The PAS-C program engaged software and hardware vendor support while refining implementation scenarios and identifying potential marketing opportunities for vendors. The PAS-C AP Suite Demonstration was conducted 19 November, 1996. The demonstration showed the functionality and interoperability of the core AP 232 and AP 209 in a real world scenario. During 1996, demonstrations of AP 209 were also conducted in conjunction with other external programs. These external AP 209 demonstrations included an Army Tank and Automotive Command (TACOM) ManTech program and a PDES, Inc. AP 209 pilot.

The PAS-C demonstration results confirmed that AP 232 and AP 209 will perform their designed

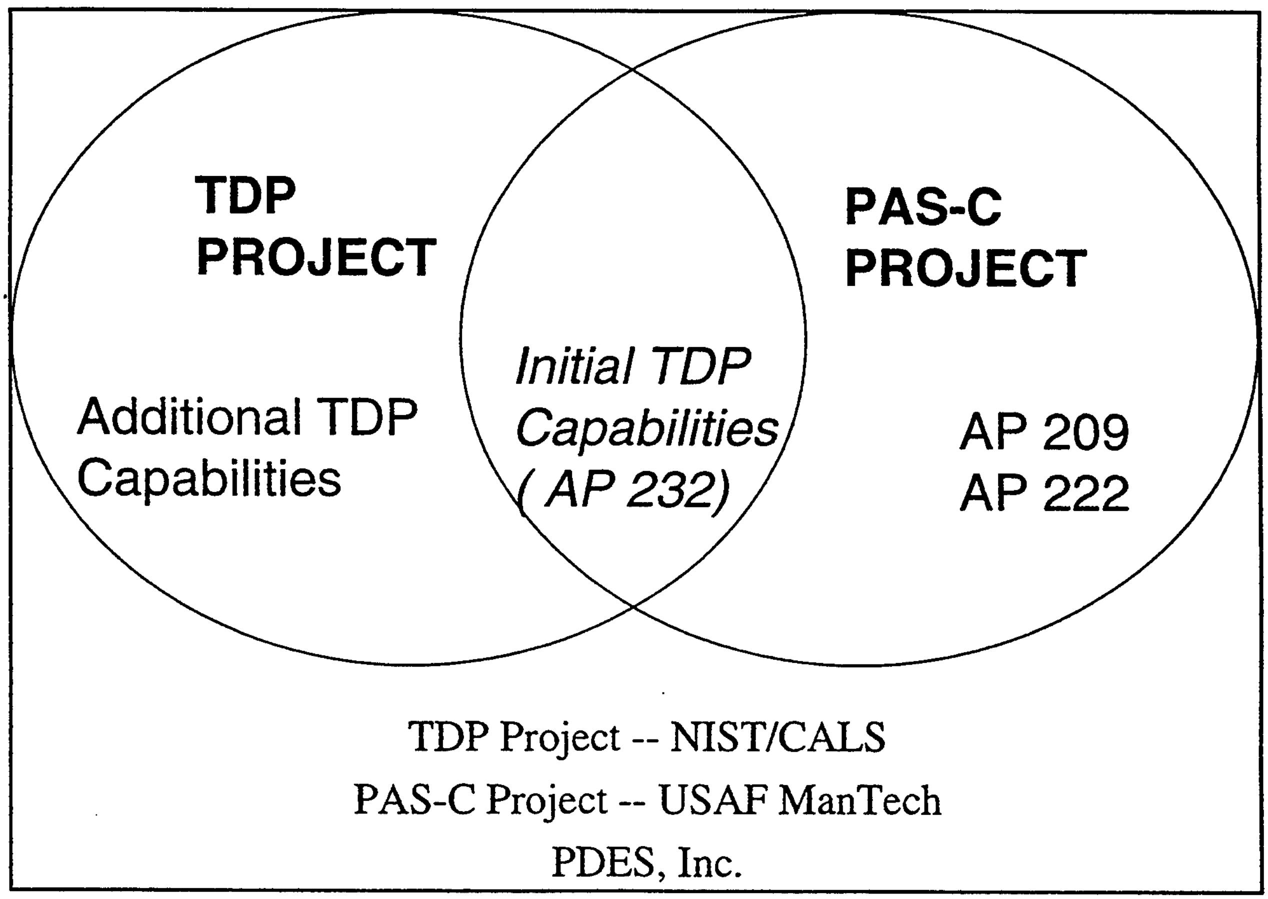

Figure 14 PAS-C/TDP Development Approach

function. In addition, the demonstration showed that the two APs are compatible with each other and are an integrated suite of Application Protocols. Their functionality was demonstrated across usage scenarios which encompassed prime to subcontractor, teaming partner to teaming partner, and prime to government interface. These interfaces were two way where appropriate and demonstrated compatibility across the heterogeneous environments which exist within and between companies.

A significant goal of PAS-C was to identify and spur development of systems and capabilities which can be utilized in the industry. The demonstrations clearly indicated opportunities where vendor products could be utilized to aid the functions within the scope of the AS. Vendor products which were available to the program at the time of the demonstrations were included in the demonstrations and their commercial availability highlighted.

The demonstration showed the use of STEP in a real world scenario between a Prime contractor and a Subcontractor. Application Protocols 203, 209, and 232 were used in the demonstration. Various commercial CAD/CAE and PDM systems were utilized. These included InSync, Metaphase, MPRS (Lockheed Martin Tactical Aircraft Systems PDM system), CATIA, MSC Aries, CCDP (a composites system developed by Northrop Grumman), Unigraphics, and PATRAN.

The suite demonstration simulated the business process of exchanging technical information among a prime contractor and a subcontractor design/analysis team as shown in **Figure 15**. The scenario can be viewed as five stages:

- Prime contractor putting technical data package of requirements together and sending them to Design/Analysis Team.
- Design Analysis perform preliminary sizing and initial design.
- Perform finite analysis on initial design.
- Create Technical Data Package of Sub-assembly and ship to Prime Contractor
- Prime Contractor incorporate Technical Data into overall technical data package for delivery to end customer.

The detailed demonstration scenario is shown in **Figure 16**.

2.3.1 Prime Contractor - Packaging of Technical Requirements

The first business process stage dealt with a Prime Contractor packaging technical requirements for a sub-assembly and sending these requirements to a Design/Analysis Team.

The Prime Contractor utilized a product data management (PDM) system to identify the placeholder parameters for the out-sourced sub-assembly. Requirement data sets for sub-assembly were then identified and prepared for shipment to Design/Analysis Team. Requirement data sets included a procurement control drawing, sub-assembly shape envelope, additional technical requirements, and meta data that packages/relates these requirement data sets together.

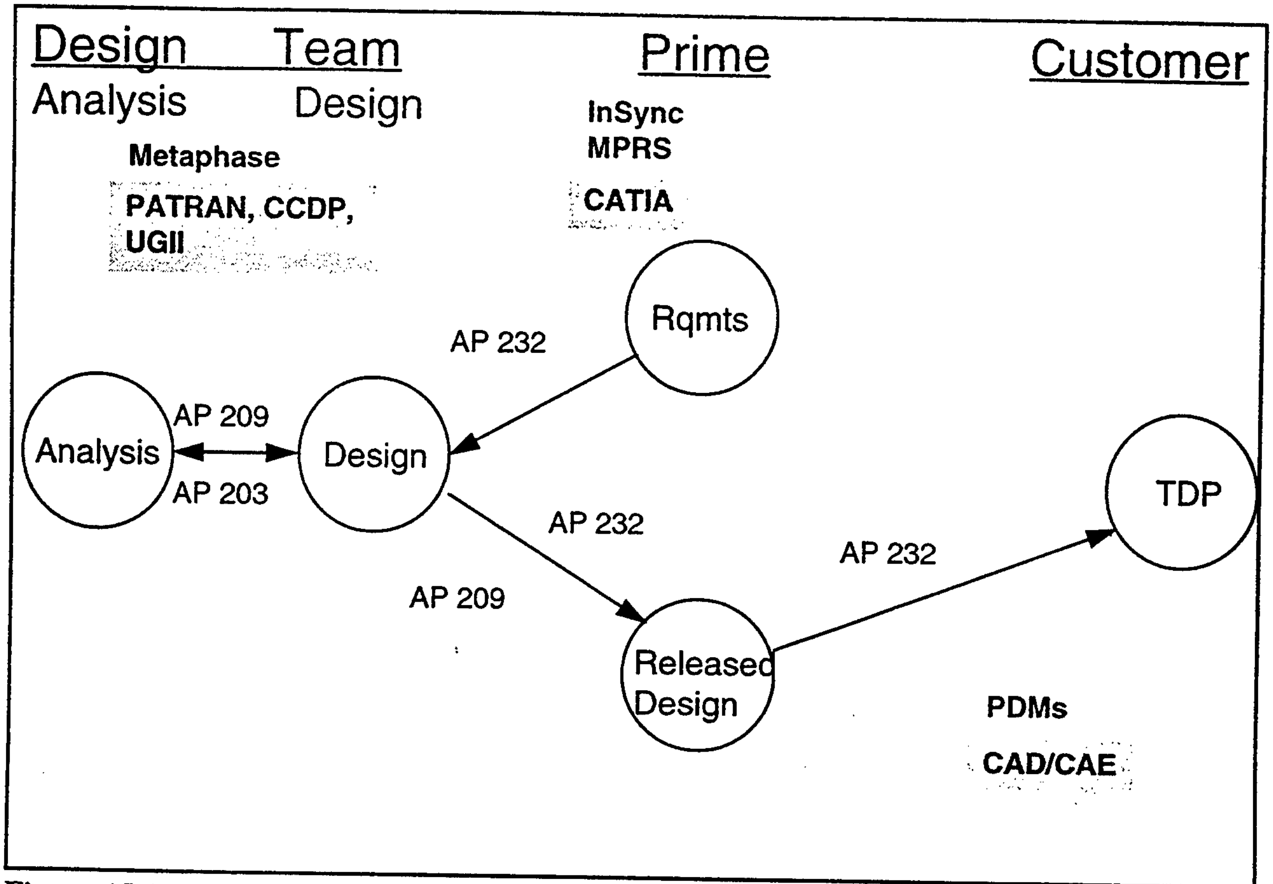

Figure 15 High Level Scenario

2.3.2 Design/Analysis Team - Preliminary Sizing and Design

The second business process stage dealt with a Subcontractor or Teaming Partner's PDM system receiving the requirement data sets from the Prime Contractor, and performing preliminary sizing and design for a sub-assembly.

The details of the above process are that the subcontractor received data files and placed them under configuration control. A Work Breakdown Structure (WBS), similar to the part breakdown structure in the PDM system, just for the sub-assembly was created to reflect proposed product structure and data to be generated in design/analysis process. This sub-assembly configuration structure within the PDM system identified the high level data that will be delivered to the Prime contractor.

A sub-assembly shape envelope was utilized to prepare shape parameter packets for individual sub-assembly components. The result of this activity provided shape information used as input to preliminary design activities such as initial structural sizing. Utilizing AP 209, the resulting shape parameter packets for structural sizing were sent to an automated composites design tool. In the design, tool ply shapes and ply tables were formulated. This initial component design was then converted to an AP 209 format.

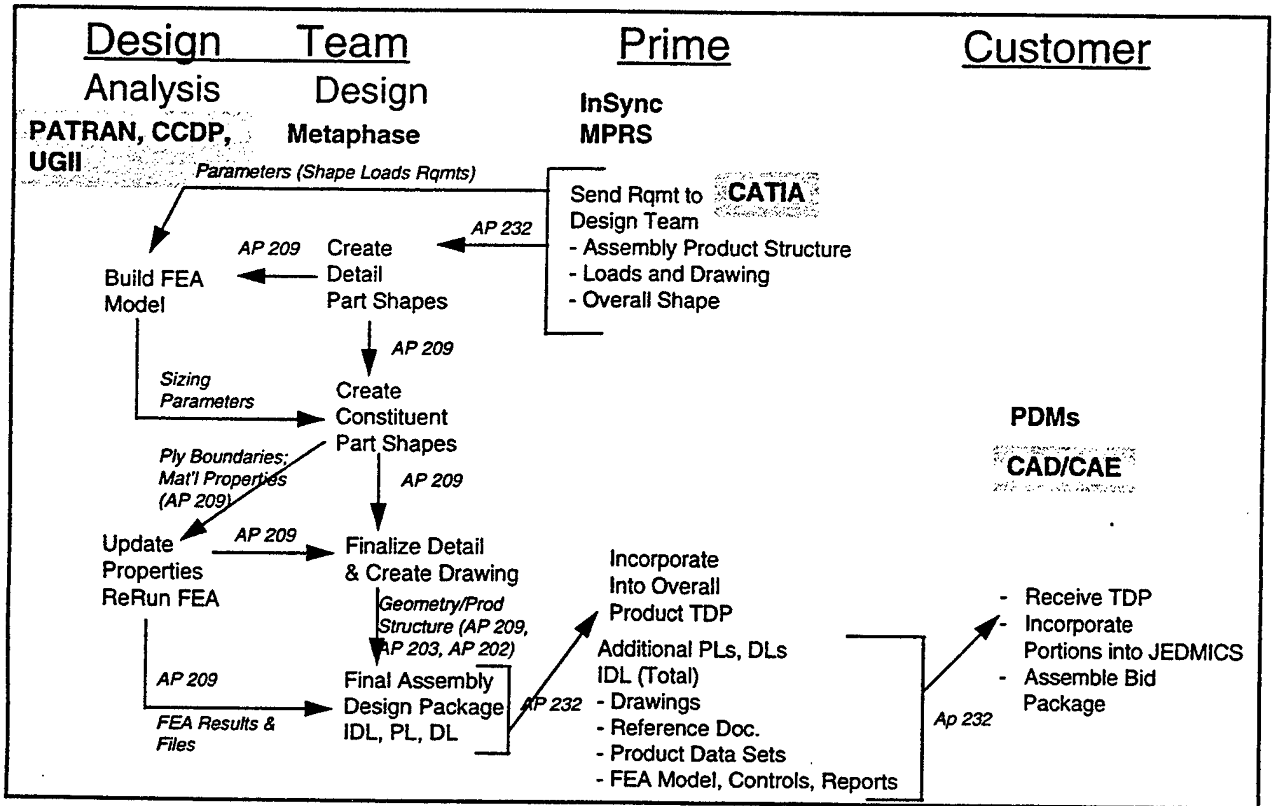

Figure 16 Detailed Demonstration Scenario

2.3.3 Design/Analysis Team - Finite Element Analysis of Detail Part

The third business process stage dealt with performing analytical structural validation of the composite component. An AP 209 file was utilized as a common storage spot to facilitate sharing and relating composite part data along different steps of the finite element analysis process.

Part shape via AP 209 was translated into a FEA pre-processor. A FEA model was generated on the FEA pre-processor. This FEA model was then translated and merged into the existing AP 209 file. Material properties for each finite element were generated utilizing the AP 209 file as input. The material properties were inserted into the FEA pre-processor and control information for the FEA model generated. The FEA controls were then translated and merged into the existing AP 209 file. A FEA solver was run against the FEA model in the FEA pre-processor. The results of the FEA solver were then both translated and merged into the existing AP 209 file, and viewed by a FEA post processor.

At this point, an iteration on the design could have occurred if the FEA result warranted it, but this was not included in the demonstration.

2.3.4 Design/Analysis Team - Technical Data Package of Sub-Assembly

The fourth business process stage dealt with performing formal documentation of the sub-assembly component. This consisted of identifying the parts list, data list (or an indentured data list), applications list, and product data sets (containing product 3D shape information) in a PDM system and translating them into a STEP formatted shipping list. Potentially, the drawing, parts list and data list could also be in STEP format. Other component and/or sub-assembly technical information were created or captured in other file formats and incorporated into the technical data package for the sub-assembly delivery to the Prime Contractor.

2.3.5 Prime Contractor - Technical Data Package of End-Item

The fifth business process stage dealt with creating/updating the technical data package for the end-item that would be shipped to the End-Customer.

In this scenario, the Prime Contractor took the Technical Data Package from the Design/Analysis team and placed the technical data in it's PDM system.

The prime contractor then created the packaging information needed to ship the updated End-Item data to the Customer. The data package consisted of information related to the component in the sub-assembly.

2.3.6 Implementation Issues

The following paragraphs discuss those implementation issues which have been identified as being most significant based on this demonstration.

Physical file exchanges have been successfully implemented using STEP. This was the implementation method utilized in the program demonstration. A Level 3 (data sharing) STEP implementation would have been the most impressive since it would foster concurrent engineering on an intercompany basis, alleviate data redundancy, and help to ensure data integrity. Standard Data Access Interface (SDAI) software capability, currently under development in the ISO community, is closely related to the technology to have a Level 3 implementation. The ability to have applications utilize standard calls for data and have databases recognize those calls will simplify software development. However, software to implement a Level 3 data base was not available for the PAS-C program demonstration.

The presentation information being developed in AP 201, AP 202 and AP 232 had no software available to populate the database, display this presentation on a screen, or plot the presentation on a paper drawing. This capability is needed to enable human readable output from STEP. Considerable vendor involvement is required before this software will be available, however, it would have added major functionally to the demonstration. This functionally would also enhance an ALC's ability to prepare a re-procurement package from this AP.

2.3.7 Demonstration Development Tasks

The following tasks were accomplished during the development of the demonstration:

- Defined demonstration requirements.
- Defined architecture.
- Defined software requirements.
- Developed software.
- Integrated software to ensure the software functioned together for cohesive demonstration.
- Created database, compiled the schemas together and parsed them into a database definition.
- Loaded database by populating the database with the information from the Air Force part.
- Conducted a dry run of the total demonstration.
- Conducted total demonstration on Air Force part.

2.4 Technology Transfer

Technology Transfer has been an important aspect of the PAS-C Program. Any time a technology is being standardized, like the exchange of composite part information, technology has to be transferred so that a consensus can be obtained. Therefore the PAS-C team has been actively involved in a multitude of technology transfer endeavors. Many of these technology transfer endeavors were embedded within required program tasks. The PDES State-of-the-Art Assessment task is a good example. The PAS-C team not only gave the developers of each STEP Part valuable feedback, but the results were also used as a reference manual for individuals who were trying to get up to speed on PDES/STEP. Another visible technology transfer was the impact the PAS-C development methodology and structure had on the concepts used in the National Institute of Standards and Technology's NIST document *Issues and Recommendations for a STEP Application Protocol Framework* [9]. PAS-C's development schedule and labor hour estimates were used to help formulate an ISO standard AP development template so that other AP projects could gain from PAS-C's experience. Other projects that PAS-C has influenced indirectly have been PDES Inc. and the Air Force ManTech PAP-E program. They both have used a Framework/Building-Block style to aid in presenting overall scope of their respective suite of Application Protocols.

On the composite part information side, terminology was obtained from the ASTM organization and the ISO technical committee on Plastics' sub-group, Composite and Reinforcements (ISO TC61/SG13). This terminology was used to ensure no conflicting terminology was created.

Technology transfer with the F-22 Program Airframe Integrated Product Team (IPT) was initiated with the sharing of information exchange requirements. Initial talks with the Air Force ManTech programs Advanced Tooling Manufacture for Composite Structures (ATMCS) and Manufacture of Thermoplastic Composite Preferred Spares (MATCOPS) led to identifying potential synergistic opportunities.

Sharing of information and methods is continuing with PDES Inc. Interoperability of application protocols is an activity in both PDES Inc. and PAS-C where harmonization is occurring. Additionally, technology was leveraged in a PDES Inc. pilot project using AP 209 for design to analysis. The PAS-C Team shared results with PDES, Inc. on this pilot. Other companies who participated in the PDES Inc. AP 209 pilot are Intergraph, ITI, Ford, MacNeal Schwendler, Northrop Grumman, and Lockheed Martin. This proved to be an excellent avenue for technology transfer.

Technology Transfer also occurred with an Army ManTech program out of the Tank and Automotive Command (TACOM). TACOM piloted AP 209 utilizing parts from their Composite Armored Vehicle Program. PAS-C provided training on AP 209 so a richer validation of the standard could be undertaken. The TACOM demonstration of AP 209 was conducted in February, 1996. Sharing of PAS-C AP 209 demonstration software was also a key factor in this successful demonstration.

This page intentionally left blank.

3 BENEFITS ANALYSIS

This section contains the Benefits Analysis conducted during the PAS-C Program.

3.1 Benefits Analysis Approach

The approach used to conduct the benefits analysis is summarized in **Figure 17**.

3.1.1 PAS-C Phase I - 1991

The dashed box in **Figure 17** identified as, 'PAS-C Phase I - 1991' is a summary of the tasks related to the Scoping and Benefits Criteria that were completed in Phase I of the PAS-C Program (see Appendix A for full list of documentation). The following subsections define the tasks that were completed as part of that overall activity.

1991 Team & Government Systems Requirements

The PAS-C Team analyzed the Team's and the Government's Systems that were in-place or were nearing production implementation. The initial analysis was a broad view of the current practices and the current systems that were used in aerospace. This initial analysis was documented as an IDEF node tree in the *Functional Needs Report for the PAS-C Program* (PASC002.01.00). As the full IDEF0 documentation was developed, the scoping and benefits approach was refined to identify several different potential areas where the highest payback could be achieved using STEP technology for data exchange.

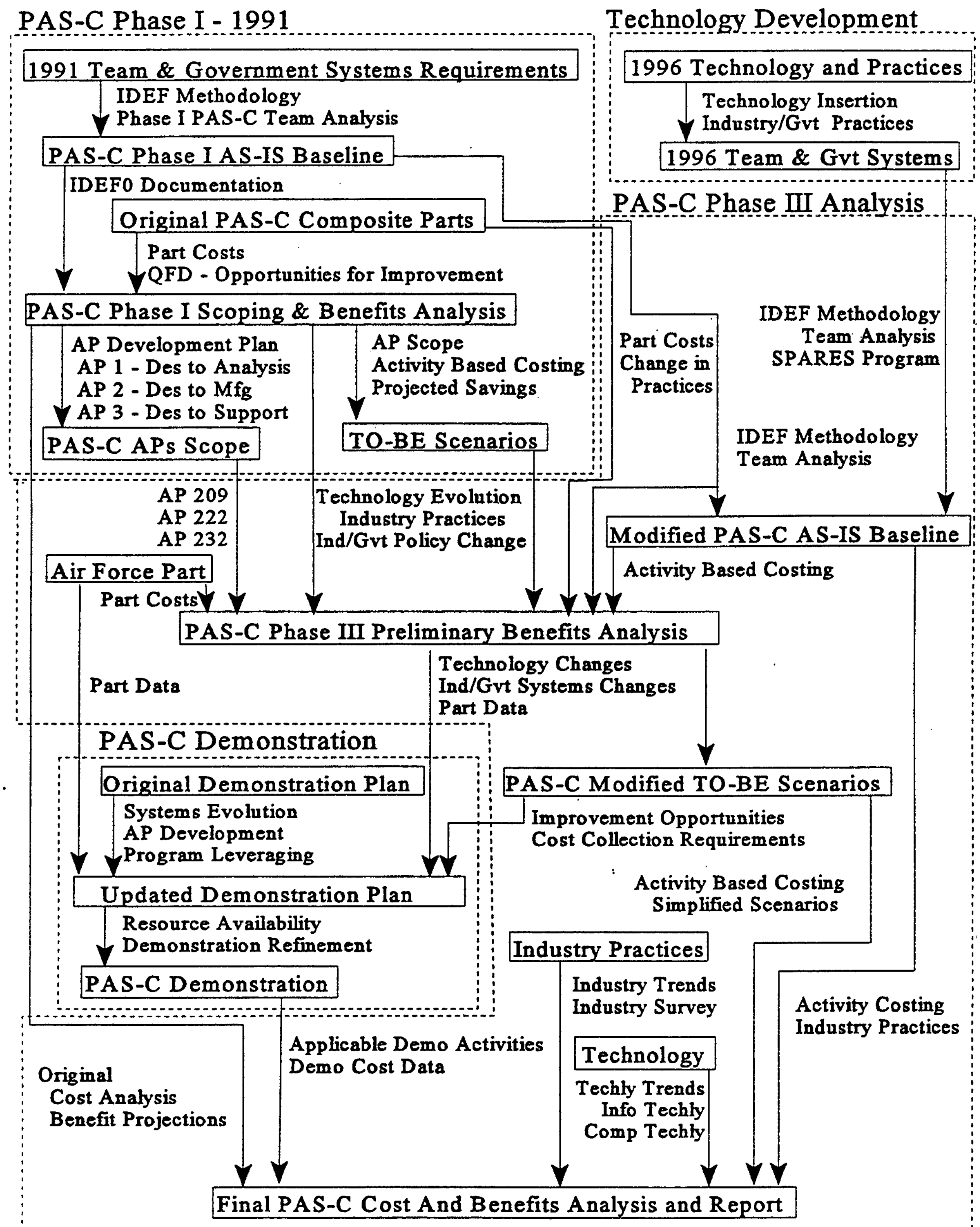

Figure 17 Roadmap to PAS-C Final Cost Benefit Analysis

PAS-C Phase I AS-IS Baseline

The PAS-C Phase I AS-IS composites baseline was represented as a full IDEF0 documentation representing the functional baseline for composites technology for the PAS-C Phase I activities and was documented in the *Functional Needs IDEF0 Activity and Information Models for the PAS-C Program* (PASC006.01.00). The higher level (i.e., general) IDEF0 activities within that document were applicable across many different types of materials: composites, metallics, ceramics, etc. The lower level activities within that document represented the peculiarities relative to the different types of composites (e.g., thermoset, thermoplastic) and the different types of composites parts (e.g., stiffeners, skins).

The PAS-C Phase I AS-IS baseline also represented the current STEP technology that was in development and nearing standardization. This is documented as the *PDES State-of-the-Art (SOTA) Assessment for the PAS-C Program* (PASC005.01.00).

Original PAS-C Composite Parts

The original PAS-C composite parts were selected early in the PAS-C Program. These three parts were considered representative of the majority of the composite parts that were in use within the aerospace industry at that time. The three parts were a contoured skin laminate, a "T" composite assembly, and a core stiffened panel. All three of these parts were actual production parts from United States Air Force programs and were identified in the *PAS-C Sample Part Set* document (PASC003.01.00). By selecting the parts early in the program, the PAS-C Team focused on what the needs of Industry were in lieu of the needs of a particular company. The focus also allowed the Team access to actual cost data for analysis and expert personnel that could evaluate the preliminary Team baseline.

PAS-C Phase I Scoping & Benefits Analysis

The PAS-C Phase I analysis brought together several different aspects of the PAS-C Program into a Quality Functional Deployment (QFD) house of quality. The QFD house of quality compared the identified needs of aerospace composites industry (relative to composite information requirements) against:

- the ability of STEP to achieve this capability;
- the risks to achieve this within the timeframe and resources of the PAS-C Program;
- the different scenarios for information exchange that would prove the most beneficial from a cost perspective for the life cycle of a composite component.

The documentation of the results of this analysis were captured in the *Scoping and Benefits Criteria* (PASC007.01.00 and PASC008.01.00) and the *Functional Needs/State-of-the-Art Comparison for the PAS-C Program* (PASC009.01.00).

TO-BE Scenarios

An output of the Phase I Scoping & Benefits Analysis was the TO-BE scenarios for data exchange. The PAS-C Program was tasked with support of data exchange for the life cycle of a composite component. Therefore, the Scoping and Benefits analysis took this into consideration relative to the AP scopes and arrived at the highest payback that could be obtained for three areas of data exchange that could provide payback over the life cycle of composite components.

PAS-C APs Scope

The scope of the PAS-C Application Protocols (APs) were initially defined in the *Scoping and Benefits Criteria for the PAS-C Program* (PASC008.01.00) and the development plan for these APs was defined in the *Development and Demonstration Plan for the PAS-C Program* (PASC010.01.00). These documents identified the plan for development of three Application Protocols based upon three areas of data exchange: Design to Analysis, Design to Manufacturing, and Design to Support. The TO-BE Scenarios determined where the highest payback for these three areas could be obtained. Phase II activities of the PAS-C Program determined the details of the data models and completed ISO procedures to obtain AP numbers for these respective areas.

3.1.2 Technology Development

The initial PAS-C Phase I activities were completed in 1992 based upon systems, technology, industry practices, and government practices prevalent in 1991. Five years have elapsed since this initial analysis and several important technologies and industrial policies have changed.

1996 Technology and Practices

The technologies that have impacted the PAS-C Program since the initial analysis are:

- **Storage Technology** - Large quantities of digital data can be stored relatively cheaply when compared with the technology available in 1991. This is in two different areas: short term storage (on-line storage) and long term storage (near-line and off-line storage). This technology has decreased the concern about the size of files and/or the on-line or near-line availability of older data for use in newer/updated applications that use the data.
- **Product Data Management (PDM) Systems** - The integration of CAX systems with database technology (and relatively cheap storage) has created the capability to manage large quantities of digital data in a single environment. Industry has recognized that the management and availability of their product data for use in newer designs has become a strategic capability for success.
- **Internet Technologies** - During the initial PAS-C evaluation, the Internet was a novelty that few people had access to, much less sufficient computing power to utilize. In the ensuing years, the Internet has become an engineering tool that can aid the Design Engineer (and Manufacturing/Tool Design Engineer) in finding standard components and related

documentation within a company (Intranet) and outside the company (Internet). The ability to access the data has also created an information overload to the individual accessing the data on the Inter/Intranet.

- **Electrical and Electronics Technology** - The electrical and electronics industry technologies evolve every two or three years. Several of these technologies require new methods to exchange data due to lack of current standards to exchange the required information (e.g., miniaturization, multi-chip modules). In many cases, the CAE vendors integrate the capability to exchange data within the vendor's product offering and the integration is sufficient to maintain market share and to remain in the market nitch that they are in. The requirement to exchange data for support (or other applications) is less important because the product is out the door and another lower cost product is in development to replace the current product offering. Replacement of the older product offering, in lieu of repair of the older product offering, is often cheaper.

This following are believed to be the major contributing policies affecting the PAS-C Program outcome. The industrial based policies that have changed since the initial analysis are:

- **Electronic Commerce** - There are several policies that have changed in this arena:
    - The classic system of purchasing components through a competitive bidding process via the US Mail with a Materials Department is being replaced with EDI processes for competitive bidding.
    - Materials Department personnel can send out bids and receive bids almost instantly with EDI capabilities. The turn around on acquisition can be shortened from 'weeks and months' to 'days and weeks' because the dead time for assimilating, sending, and receiving materials is almost eliminated.
    - Designers can access standard components over the Internet/Intranet for identification of newer and/or lower cost components that can satisfy a need in a new design.
- **Contractor Logistic Support (CLS) for Weapon Systems** - Newer DoD weapon systems are becoming more and more complex in their design and support requirements. The technology has helped the maintainer keep up, but fewer weapon systems, fewer numbers of a particular weapon system, the complexity of weapon systems, the fast pace of technological change, and the general downsizing of the government infrastructure have forced the DoD to initiate CLS activities for newer weapon systems.
- **Government Oversight in DoD Programs** - The oversight by government personnel in the development and production of DoD weapon systems has grown over the years to a point where many approaches, processes, and milestones are set by government regulations, standards, and specifications. To ensure that the Contractor is following the government guidance, the government places regulators, inspectors, auditors, etc., within the DoD Contractors facilities to ensure compliance. The cost to the government for maintenance of these personnel and for the Contractor to slow and/or stop work to respond to government personnel questions has risen over the years but is now starting to decrease.
- **Government Regulations, Specifications, and Standards** - The number of government regulations, specifications, and standards has driven many of the smaller companies out of

the DoD weapon system development because of the overhead cost to maintain the required personnel to follow the FARs, DFARs, government specifications, government standards, and the public laws that are not directly related to the performance of the product. Even within different contracts for the Air Force, the requirements can differ based upon when the contract was won. In the last few years, regulations have been identified as one of the cost drivers in development of new systems and the DoD has initiated acquisition reform to reduce the government instituted requirements whenever a commercial equivalent is being followed within a company. ISO 9000 is one of the commercial equivalents that is being implemented within aerospace companies to reduce the government requirements that are applied to contracts.

- **DoD Share of High Technology Company Business Base** - The DoE and the DoD were the principle drivers behind the development of high technology products. With the American public appetite for high technology products that reduce stress and/or simplify life, the principle drivers behind the development and/or refinement of high technology products has become the free market system (i.e., industrial base) that is attempting to satisfy the needs instead of the DoE and the DoD.
- **DoE and DoD Budget** - The DoE and the DoD budget have been reduced significantly in the last several years. This has affected the ability of the DoD and the DoE to lead in the research and technology development required for the next generation of Weapon Systems. The DoD and DoE industrial base have also suffered as the DoE and DoD budgets are focused on sustainment in lieu of development.

There are other policies, including the more wide spread use of the ISO standards, that have changed since the initial PAS-C analysis. Most of these changes have been seen as beneficial to the overall objectives of the PAS-C Program. One drawback to using ISO standards is the time required for developing an ISO 10303 standard is several years and technology may change over this time frame in such a manner that the standard may become obsolete before it is even a standard.

1996 Team & Gvt Systems

Many of the PAS-C Team and Government Systems have changed since the initial analysis of the PAS-C Program. In the many cases, the 1990 and 1991 systems that were in place were slated to change to more modern, efficient systems due to supplier - contractor relationship changes, and/or "Best of Breed" systems.

For government systems, this included the migration of the respective service systems to "Best of Breed" Systems for the entire DoD. An example of this is the migration of Air Force EDCARS, Army DSREDS, and Navy EDMICS to the DoD "Best of Breed" System (JEDMICS). Each of the legacy systems performed the same basic functions and was produced by a different system vendor. It was viewed that this was a great inefficiency to pay for three (or more) different systems that had the same basic functions, therefore each system was evaluated and a "Best of Breed" was selected. The "Best of Breed" would be enhanced to a level whereby the system could accommodate all the service's requirements and the legacy data would be migrated to the "Best of Breed" System.

In the contractor environment, system changes have happened due to two principle factors: change in contracting relationships, and technology insertion. As an example of changing contracting relationships, Northrop has merged with Grumman and is now Northrop Grumman. Northrop Grumman has acquired Vought who is now Northrop Grumman Commercial Aircraft Division (CAD). Vought was producing the B-2 and was working with Northrop to that end. The CAD/CAM System of choice for the B-2 was CADAM and NCAD/NCAL. Northrop Grumman CAD is redesigning C-17 components in UGII. NCAD/NCAL is a proprietary system, while UGII is a commercially available system.

As an example of technology insertion, Lockheed Martin has migrated the Multi-Program Release System (MPRS) from an IMS based system (i.e., hierarchial DBMS) to a DBII System (i.e., relational DBMS).

Six years is a long time in today's fast paced technology environment. The technology and practices identified in Section 3.1.2 have impacted most systems evolution over this time frame.

3.1.3 PAS-C Demonstration

The PAS-C demonstration was the initial proof of concept that the PAS-C developed APs worked as a suite of data exchange standards in a real world data exchange example.

Original Demonstration Plan

The *Development and Demonstration Plan for the PAS-C Program* [10] was developed in 1992 and identified the initial plan for demonstrating the PAS-C suite of APs that were to be developed. It took into consideration the current SOTA of the STEP standard, the current systems that were in place at the respective PAS-C Team members, and the current systems that were in use at the USAF ALCs.

Updated Demonstration Plan

The updated *Demonstration Plan for the PAS-C Program* [11] was developed in 1996 with the systems that were in-use at the time of the demonstration utilizing as much of the currently developed PAS-C APs as possible with the available resources. Since the final demonstration scenario was focused on a redesign process to prove out as much of the PAS-C developed APs as possible, the use of the initial parts identified for the program was not beneficial because none of these parts have undergone any redesign effort. Therefore, a part was selected that has undergone a redesign effort from a metallic part to a composite part. The selected part was not in the initial selection 'opportunity list' because it was metallic at the time. The redesign process from a metallic to a composite part allowed the PAS-C developed APs to prove that they were robust enough for randomly selected parts (composite or metallic) that were being developed by industry. Specifically, the demonstration part was not a PAS-C Team member developed component.

PAS-C Demonstration

PAS-C developed products were leveraged in many differently programs and demonstrations during the course of the program. The expectation of the PAS-C demonstration was to prove out the 'proof of concept of the suite' of PAS-C APs as well as the ability of the PAS-C APs to work with other APs that under development or in use within industry today.

The demonstrations that are contained within this box include the demonstrations that were leveraged from the PAS-C Program. Each of the leveraged demonstrations was a different implementation of the respective AP. Each demonstration was for a unique scenario and utilized different systems for different functionality prove out of the respective AP. The results from these demonstrations is documented in Section 3.2.

3.1.4 PAS-C Phase III Analysis

The PAS-C Phase III analysis started in 1996 with development of the planning diagram in **Figure 17** to map out what has happened since the initial PAS-C Phase I analysis. The areas that would require modification and evaluation were mapped out in **Figure 17** and efforts were applied to evaluate those respective areas.

Modified PAS-C AS-IS Baseline

The PAS-C baseline for the composite design process has evolved since the initial analysis. This was primarily due to technology evolution and the use of the technology within the PAS-C Team member respective companies and industry as a whole. The modified AS-IS baseline activity scenarios were captured within the AAM of the respective PAS-C APs. The utilization of the PAS-C APs and the resulting changes due to the use of the APs is also documented within the respective AAM of the AP and within the Appendices of the respective AP. The area that required significant modification from the original baseline was the 'Design to Support' area. This area required the most significant modification due to the Technology Developments and Industrial and Government policy changes that are identified in Section 3.1.2.

Air Force Part

The PAS-C SOW indicated that an Air Force selected part would be utilized in the final PAS-C demonstration so that the data model(s) and the demonstration would not be focused on a certain type of part and/or a certain method of representing information for the PAS-C APs. The availability of the 'wildcard' part information that the Air Force was to utilize in the final demonstration was limited due to the proprietary nature of each company's approach to composites development and production. Therefore, Northrop Grumman recommended and the Air Force approved a part that was available through a program that they were working on for the C-17 Program.

PAS-C Phase III Preliminary Benefits Analysis

A preliminary analysis of the coverage of the developed PAS-C APs to the original plan identified where the APs would have the most benefit for demonstration purposes and provide the most opportunity for the reviewers to evaluate the capabilities and benefits of the respective APs. This information, the available Air Force 'wildcard' part information, technology changes, STEP direction, technology development, available resources, and other factors identified in **Figure 17** were evaluated before the final demonstration plan was completed. This analysis also considered the importance of being able to capture cost information for feedback into the final report.

PAS-C Modified TO-BE Scenario

The modified cost baseline between the original part cost in 1990 dollars versus the part cost in 1996 is based upon person-hour calculations and the average labor for industry for the respective time frame and discipline.

Industry Practices

The changes in Industry practices for the final benefits analysis were evaluated and are documented in Section 3.1.2.

Technology

The changes in Technology for the final benefits analysis were evaluated and are documented in Section 3.1.2.

Final PAS-C Cost and Benefits Analysis Report

This document is the PAS-C Final Technical Report and Benefits Analysis.

3.2 Demonstrations Used in the Benefits Analysis

This section is a synopsis of the demonstrations and pilots and their coverage of the respective APs that were used to ascertain the benefits for the final PAS-C Cost and Benefits analysis.

3.2.1 TACOM Demonstration

The TACOM project was an implementation and demonstration of a substantial subset of AP 209 in the context of design and analysis of composite automotive parts for military and civilian applications. The TACOM demonstration scenario is defined in *Implementation of STEP for Composite Automotive Components* [12] and shown graphically in **Figure 18**. The work was performed under the support of the US Army's Tank-Automotive and Armaments Command (TACOM) which is currently in the process of designing and demonstrating an armored vehicle built substantially of composite materials. The components were from TACOM's Composite Armored Vehicle Advanced Technology Demonstrator.

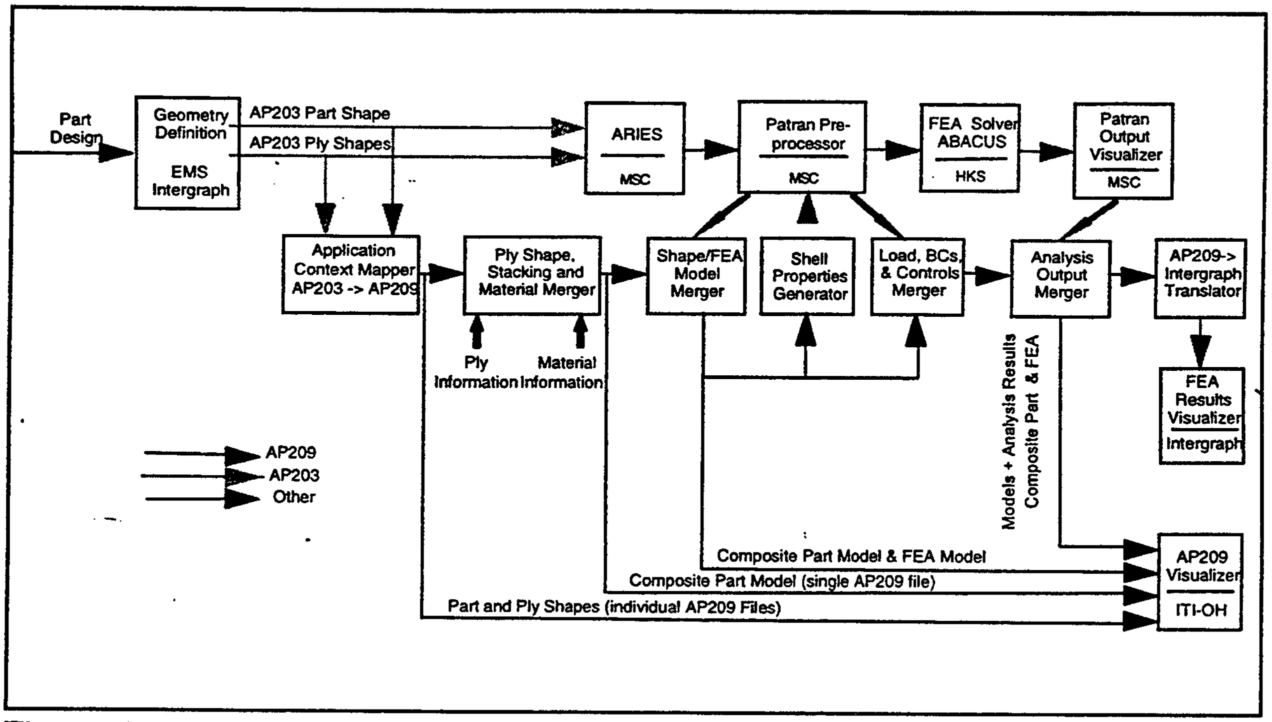

Figure 18 TACOM Demonstration Scenario

The intent of that project was to:

- demonstrate AP 209's applicability for design and analysis of composite automotive parts,
- demonstrate the exchange of design, material, and analysis data and results in a heterogeneous hardware/software environment using AP 209 as the information model and the STEP exchange format (ISO 10303-21) as the medium of delivery,

- demonstrate the applicability of AP 209 as a comprehensive application protocol for iterative design and analysis of composite parts, the archiving of such data, and product re-engineering, and
- provide substantial input from the perspective of automotive part design to the AP 209 development process.

This project delivered a fully functional demonstration of the design and analysis of selected composite automotive parts using vendor-developed software, custom software developed as part of the project, and STEP software developed in other STEP pilot projects. Also, it provided valuable feedback to the developers of AP 209 from the perspective of automotive design.

When the system flow is mapped into the generic FEA view of data exchange, the highlighted areas of Figure 19 were exercised. From this mapping and the mapping from the other demonstrations, the final Cost/Benefits for AP 209 were ascertained and are documented in **Figure 31**. The TACOM demonstration had coverage of the AP 209 ARM and AIM as defined in Table III.

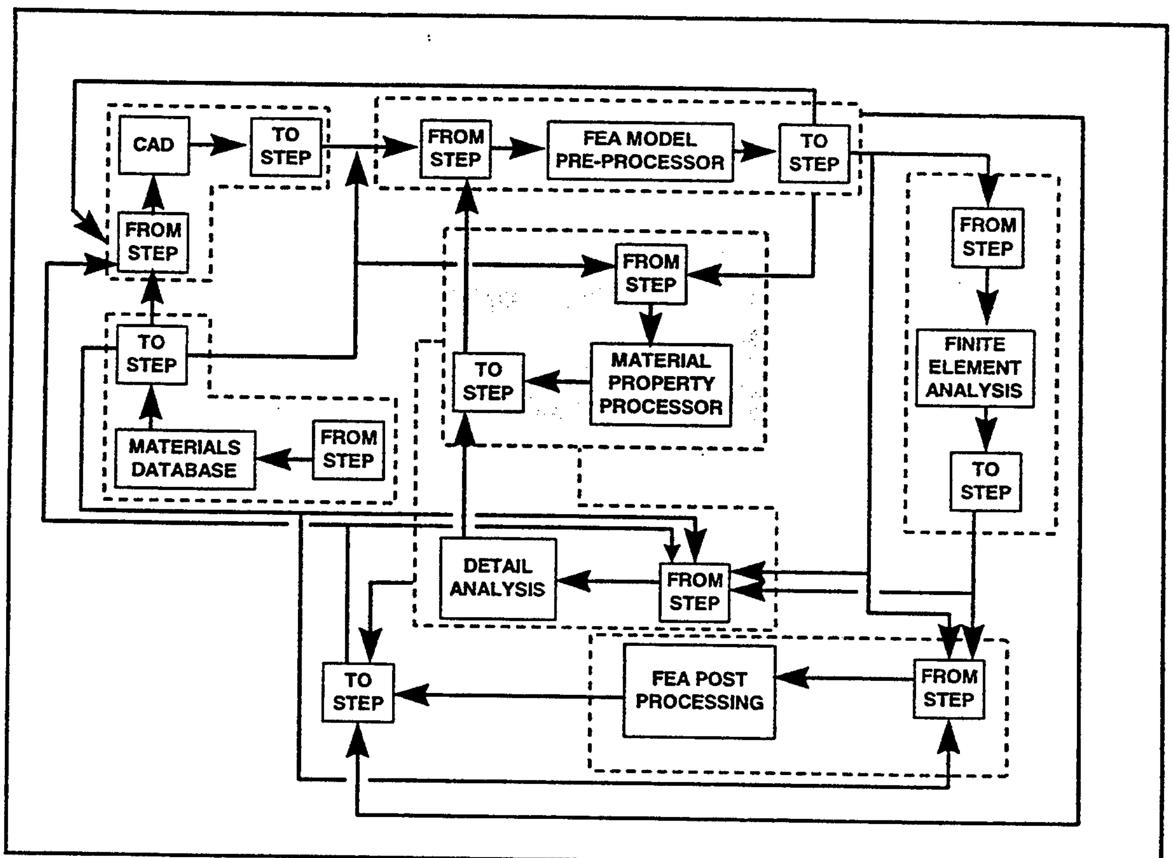

Figure 19 TACOM Demonstration Coverage of Generic FEA Data Exchange

Table III - Demonstration Coverage of AP 209 ARM/AIM Data Elements

Program	AP 209 Coverage		AP 209 Data Coverage
	ARM	AIM	
PAS-C Demonstration	50%	41%	Wireframe Geometry Composite Ply Information FEA Results FEA Loads FEA Boundary Conditions Material Configuration Management Subset
PDES INC. FEA Pilot Phase I	40%	35%	Wireframe Geometry B-Rep Solids Geometry FEA Results FEA Loads FEA Boundary Conditions Material Configuration Management Subset
MADE Demonstration	55%	43%	Wireframe Geometry B-Rep Solids Geometry FEA Results FEA Loads FEA Boundary Conditions Material Configuration Management Subset
TACOM Demonstration	46%	38%	Wireframe Geometry Composite Ply Information FEA Results FEA Loads FEA Boundary Conditions Material Configuration Management Subset

3.2.2 PDES, Inc. FEA Pilot Demonstrations

There are two phases of the PDES, Inc. FEA pilot. The Phase I activities were completed in 1996 and the Phase II activities have been initiated and are scheduled to continue through 1998.

3.2.2.1 Phase I FEA Pilot

The Phase I FEA Pilot systems flow is shown in **Figure 20** and was for a Ford Motor Company metallic crankcase component that was defined in the ComputerVision system using solids geometric construction techniques. LMTAS, Boeing, ITI-OH, MSC, GM, and Ford were the pilot project participants.

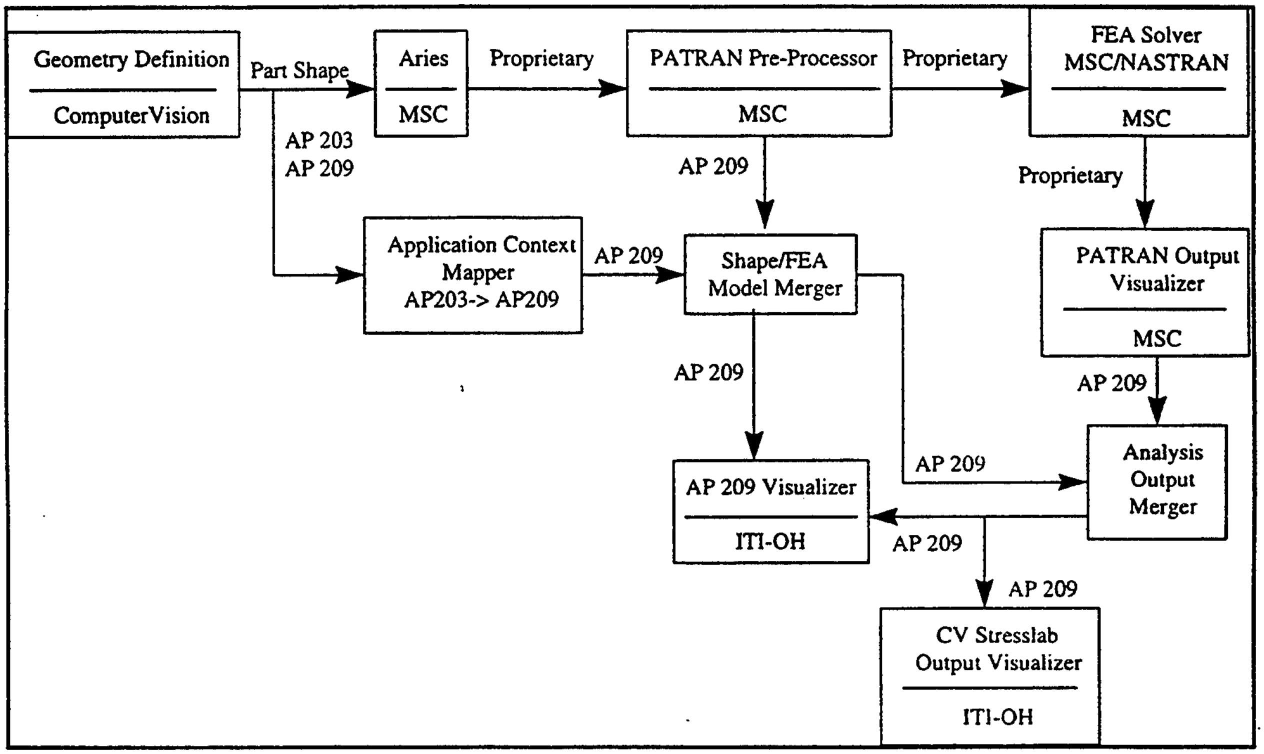

Figure 20 PDES, Inc. Phase I FEA Pilot

When this system flow is mapped into the generic FEA view of data exchange, the highlighted areas of **Figure 21** were exercised. From this mapping and the mapping from the other demonstrations, the final Cost/Benefits for AP 209 were ascertained and are documented in **Figure 31**. The Phase I FEA Pilot had coverage of the AP 209 ARM and AIM as defined in Table III.

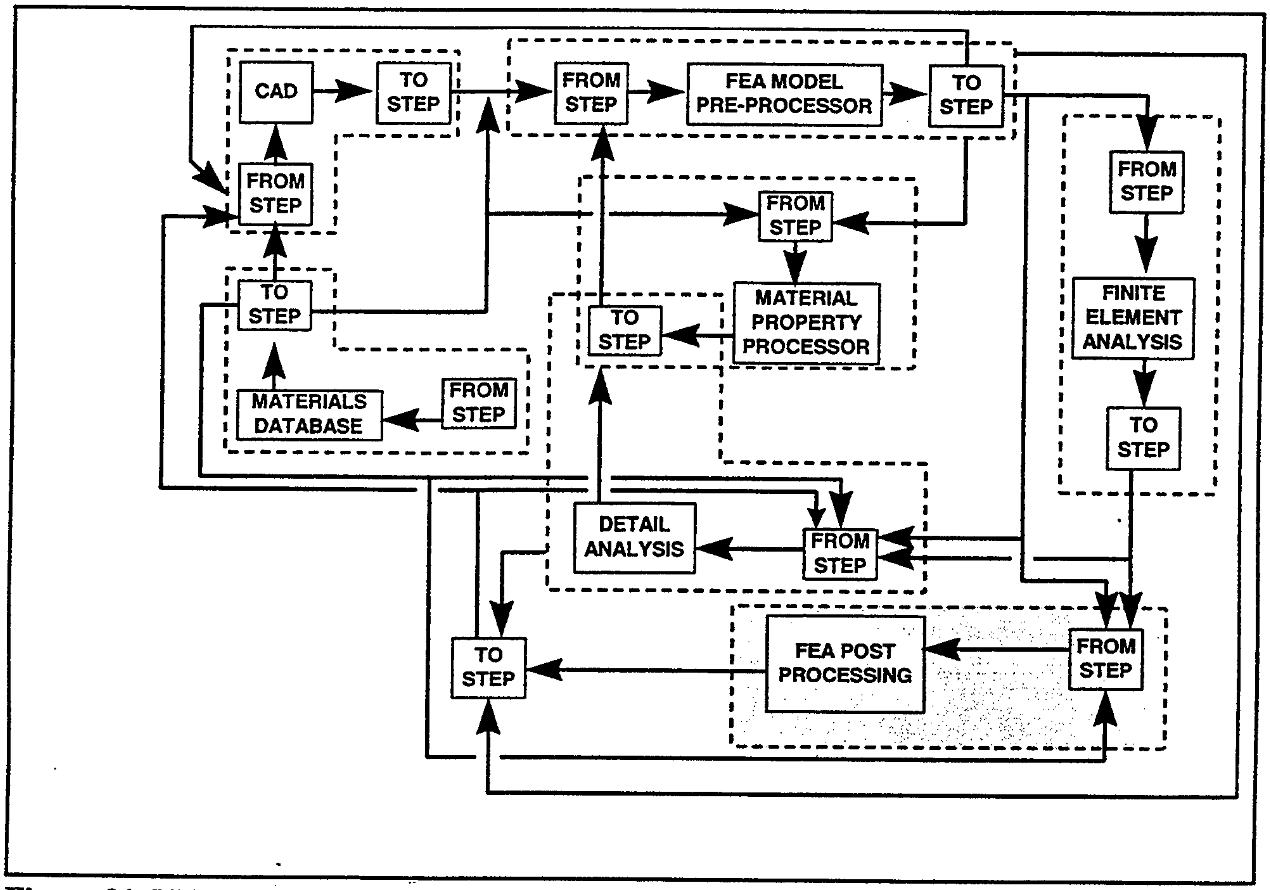

Figure 21 PDES, Inc. Phase I FEA Pilot Mapped into FEA Generic Data Exchange

3.2.2.2 PDES, Inc. Phase II FEA Pilot

The PDES, Inc. Phase II FEA Pilot is being initiated and will extend the capabilities of the first pilot to include more functionality. Members of the pilot are LMTAS, Boeing, MSC, and NASA Lewis & Langley. Details of the pilot are in development, but initial COTS systems that are being evaluated for incorporation into the demonstration scenario are NASTRAN, ElFini, Abacus, Ansys, and CATIA. A Boeing composite application is also under evaluation for the pilot that would focus on utilization of the composites information for the laying of composite tape for a part. The parts that are under evaluation are an F-16 wing skin and/or a turbine compression blade. Personnel involved in the program have identified the generic capabilities that would be exercised in **Figure 22** (when mapped to the FEA generic view of data exchange).

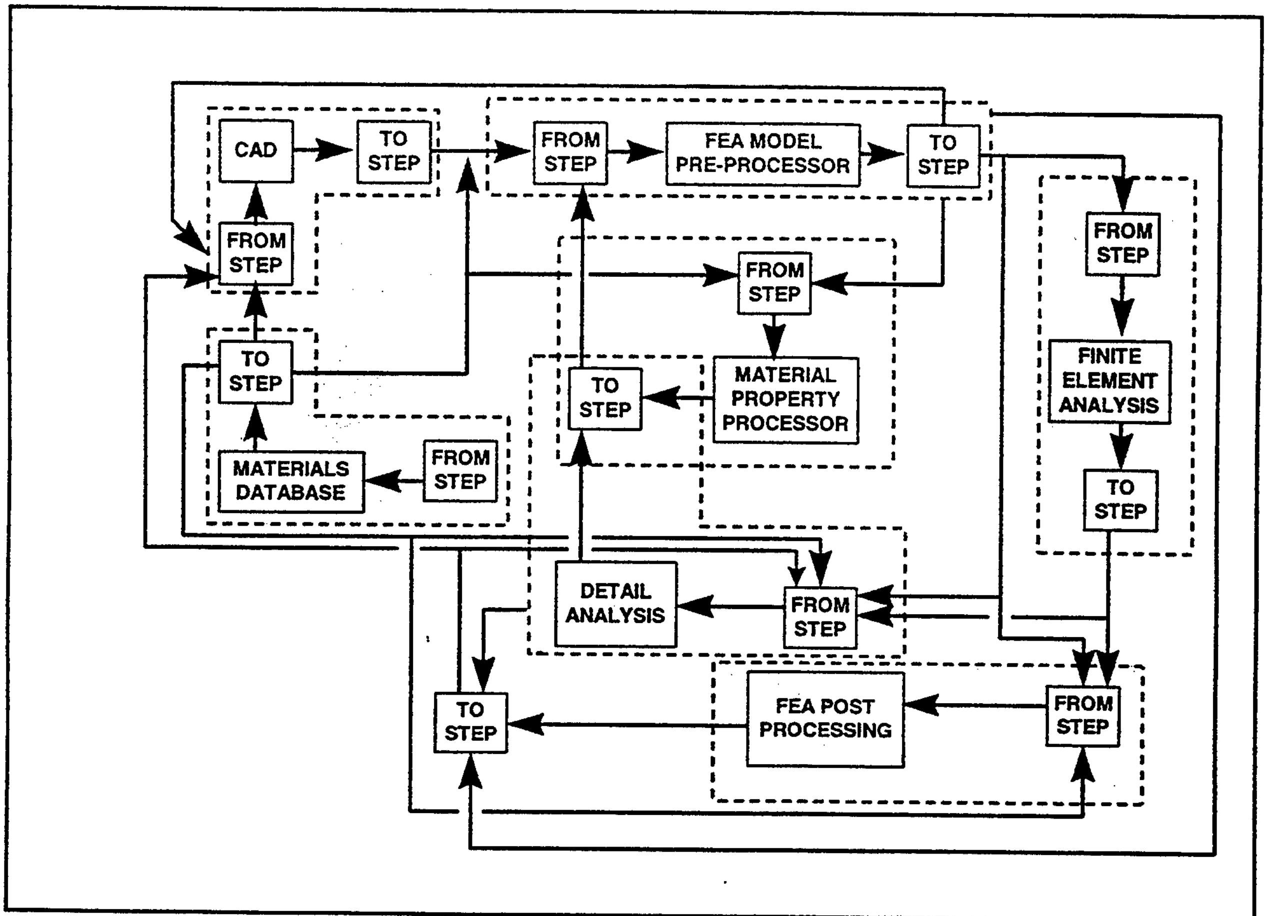

Figure 22 PDES, Inc Phase II FEA Pilot Mapped into FEA Generic Data Exchange

3.2.3 MADE Program

The MADE Program is a DARPA Program with participants from Boeing Defense & Space Group, Arizona State University, and the MacNeal-Schwendler Corporation. The program's goal is for an integrated data environment that utilizes a common vocabulary design and data reuse. The MADE Program is utilizing AP 209 for many of the data exchanges. The project was initiated in 1996 for initial prototype development, with larger scale implementation in 1997 and 1998. The 1996 effort will result in the prototype in **Figure 23**. As can be seen, there are many aspects of AP 209 that are used in the data exchange scenario. **Figure 24** contains the details of the second part of the initial prototype where many of the file exchanges are to be replaced with an SDAI access to the Shared Data Manager (SDM). The initial phase of the MADE Program will result in SDAI access for the entire model and not physical file exchanges. The second phase will extend the work in the initial phase to include Manufacturability Evaluations, Multiple Design Iterations, Version Management, Change Notification, Workflow Management, and CEM Vocabulary Integration. The demonstration scenario is given in **Figure 25** and **Figure 26**. **Figure 27** is the MADE demonstration scenario mapped into the FEA generic view of data exchange. This mapping shows the utilization of AP 209 for some of the largest utilization of capabilities for data exchange. The utilization for AP 209 ARM

and AIM is identified in Table III.

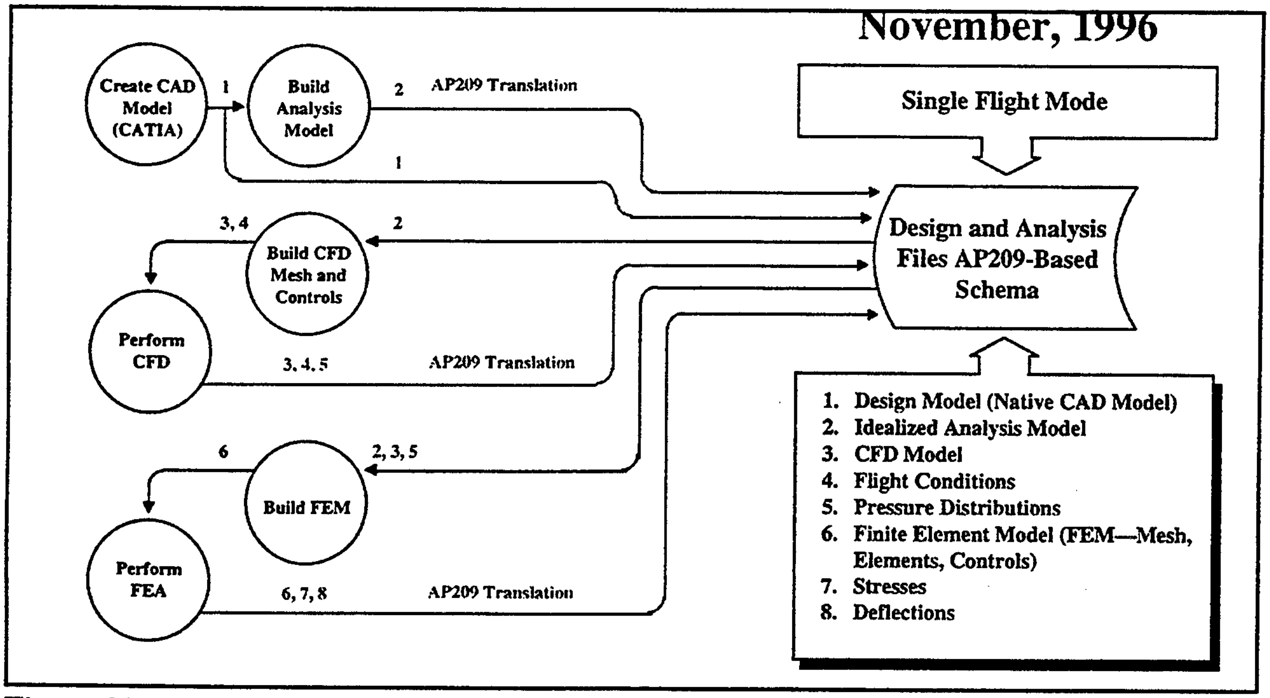

Figure 23 MADE Initial Prototype

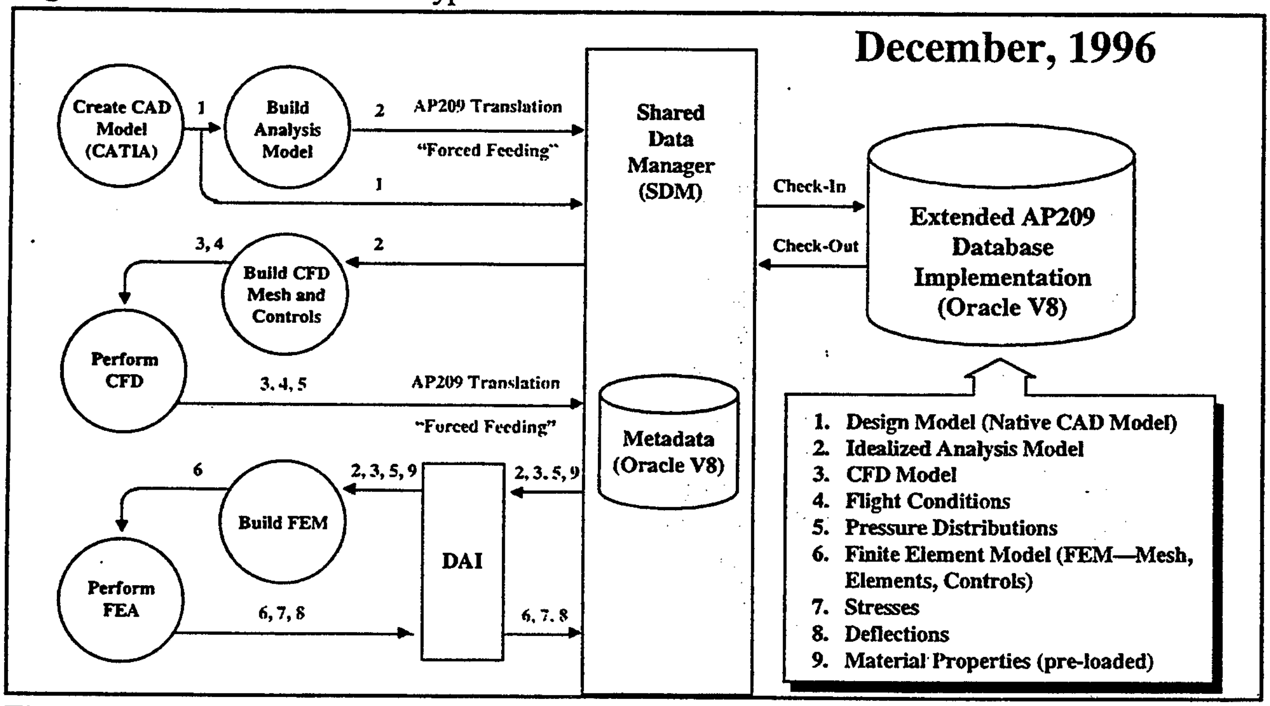

Figure 24 MADE Prototype Phase II

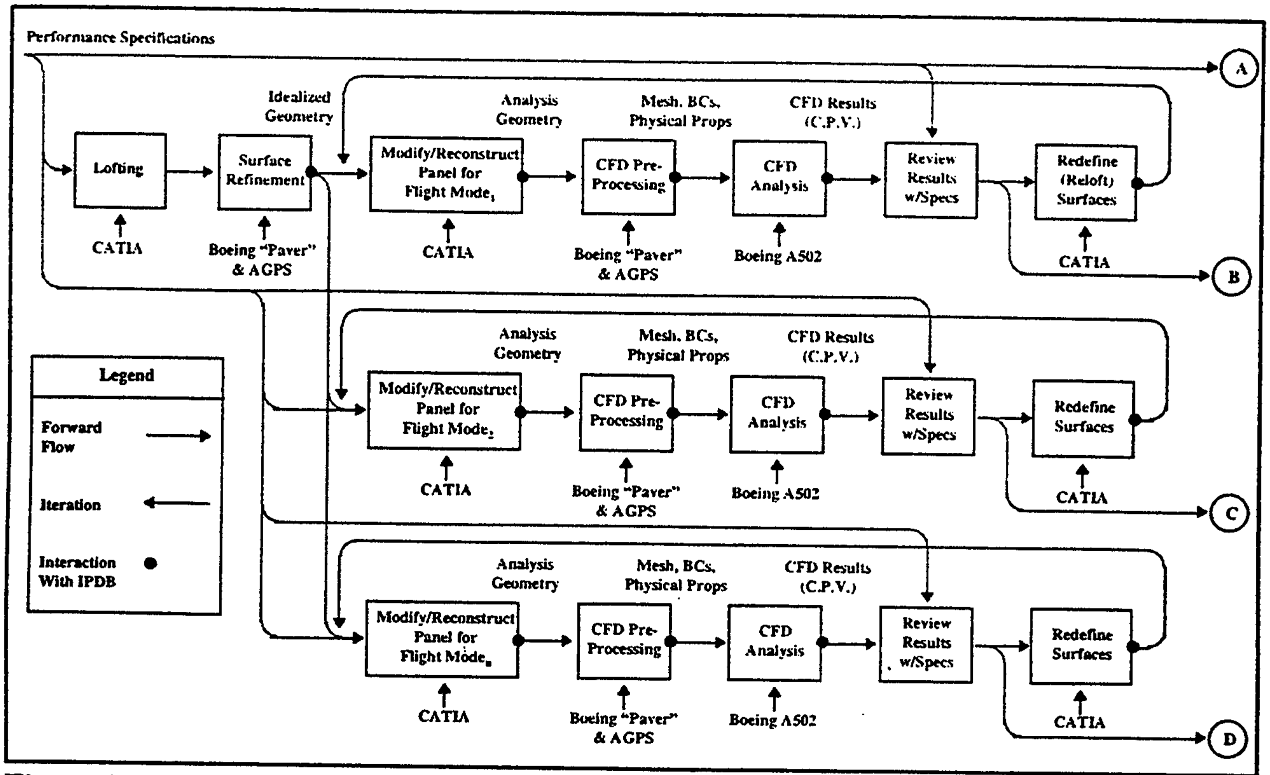

Figure 25 MADE Demonstration Flow - Part 1

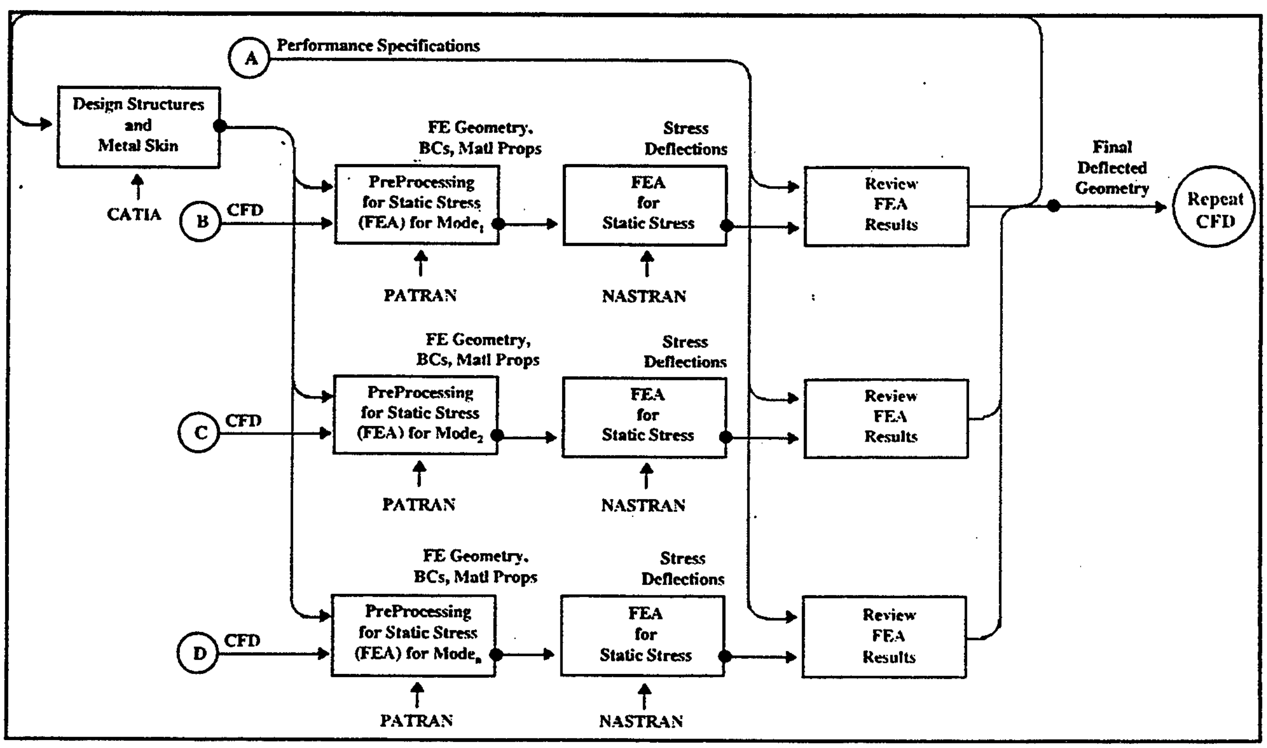

Figure 26 MADE Demonstration Scenario - Part 2

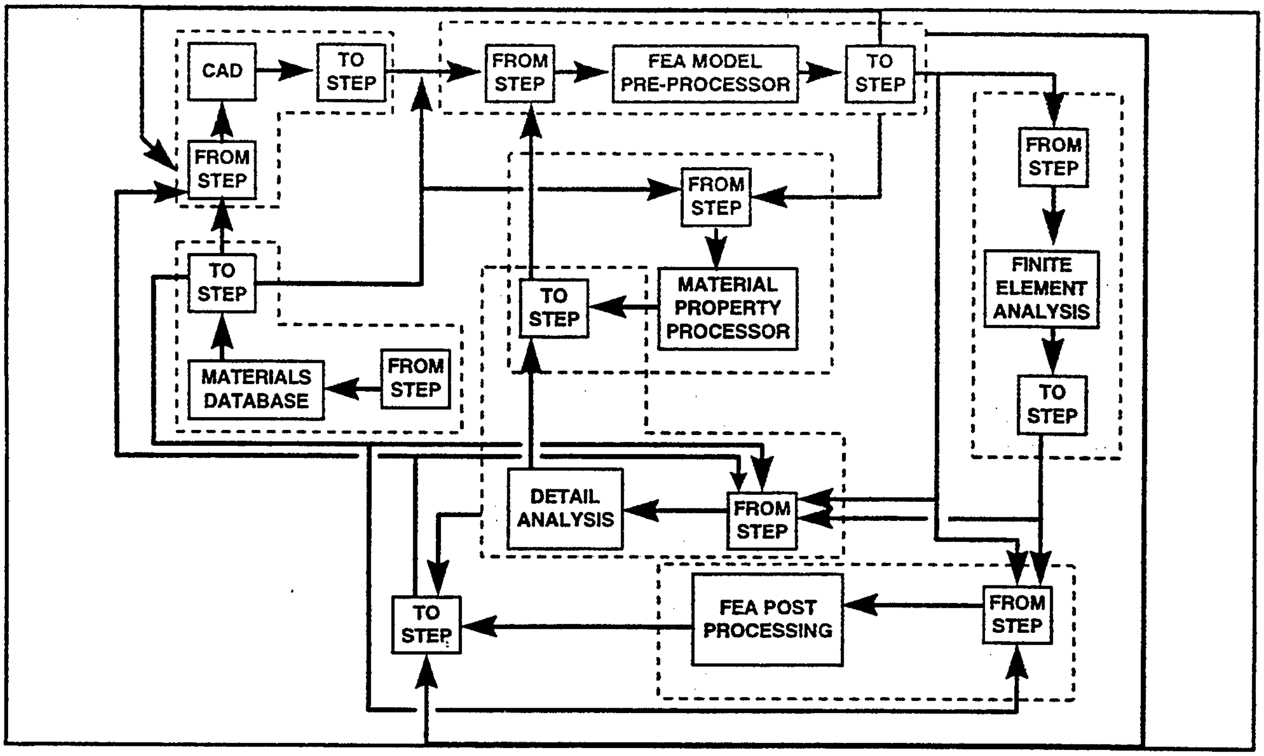

Figure 27 MADE Demonstration Mapped into FEA Generic Data Exchange

3.2.4 PAS-C Demonstration

The final demonstration plan for the PAS-C demonstration is documented in the *Demonstration Plan for the PAS-C Program* [11]. The demonstration plan identifies the systems that were used and the objectives that were to be met as part of the demonstration. The results of the demonstration and the feedback from the user community are documented in the *Demonstration Results for the PAS-C Program* [13]. The personnel that attended the demonstration represented Government (logistics, research, development, and operations), DoD prime contractors, DoD subcontractors, and commercial off the shelf software suppliers. In general terms, the response from the personnel in attendance was that the demonstration was representative of what the environment was within industry today and set reasonable expectations for the proof of concept that was required to implement the respective PAS-C APs. The mapping of the PAS-C demonstration into the FEA generic data exchange scenario is identified in **Figure 28.** This identifies that the PAS-C demonstration did not utilize all aspects of AP 209 for the PAS-C demonstration, but due to the broad capabilities of AP 209 and the limited amount of resources, this was not seen as a negative. The coverage of the PAS-C demonstration to the utilization for AP 209 ARM and AIM is identified in Table III.

The PAS-C demonstration coverage for AP 232 was in the utilization of the Data Definition Exchange (DDE), or shipping list, for data exchange between two enterprises. The PAS-C Team

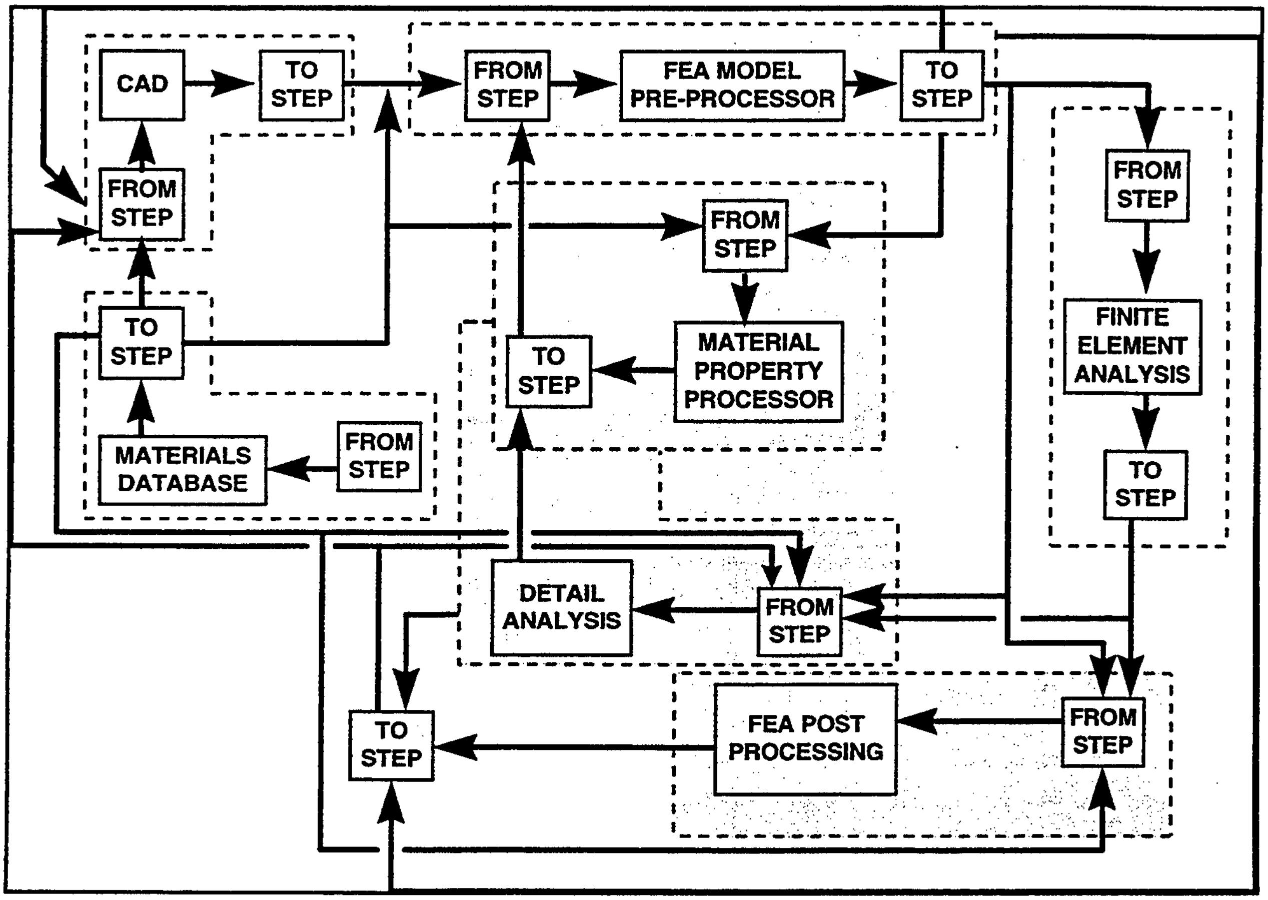

Figure 28 PAS-C Demonstration Mapped into FEA Generic Data Exchange

did not create a generic data exchange scenario for the DDE because the DDE has the capability for an unlimited set of data exchange scenarios within industry and government. Therefore, the mapping of AP 232 into a generic data exchange was not completed. The coverage of the AIM and the ARM elements for AP 232 is contained in Table IV. Relative to coverage of the DDE data elements, the PAS-C demonstration covered 60% of the DDE ARM elements.

Table IV - PAS-C Demonstration Coverage of AP 232 ARM/AIM Data Elements

AP 232 Coverage		AP 232 Data Coverage
ARM	AIM	
37%	47%	File Information per File Top Down Breakdown by Part Top Down Breakdown by Drawing/Document Document Information per File Configuration Management Subset

3.2.5 GEM Program

The Generic Engineering Model (GEM) Project is one of the projects in the context of Computer Integrated Manufacturing & Engineering (CIME) of the European Specific Program for Research and Development in Information Technology (ESPRIT) sponsored by the European Union (EU) Directorate-General XIII. While the details of the use of AP 209 are not fully known at this time, this ESPRIT Project appears to be utilizing AP 209 as a resource for development and demonstration efforts.

The aim of GEM is to integrate all the software applications relevant in the different phases in engineering analysis by exchange of results in an open and standardized way (involving the ISO STEP standard). This will improve both efficiency and quality of the analysis activities and thereby the outcomes of these activities.

The aim of the GEM project is to improve the efficiency of European industry by enabling engineering analysis methods such as FEA or CFD to be used more effectively within the design process throughout a product's life. To achieve this aim, the following objectives have been set:-

> To develop a Generic Engineering Analysis Model which can be used for the exchange, data sharing and archival of engineering analysis models. The GEM will be general enough to support a range of industrial applications, a variety of design and analysis methodologies, and the use of analysis results in the design model.

More detail can be obtained from the GEM homepage on the WWW:

www.tno.nl/instit/bouw/project/gem.html.

The GEM Project is identified here as an AP 209 related demonstration that will occur in the next several years as the project evolves and defines the details of their program.

3.2.6 LMTAS VDE Environment

LMTAS has a broad initiative called the Virtual Development Environment (VDE) that is supporting the efforts of the Joint Strike Fighter (JSF) Program. One of the projects within this initiative is the Engineering Analysis Product Data Model (EAPM). The EAPM has taken the AP 209 structure and identified the applications that could be sharing information with the AP 209 structure as shown in **Figure 28**. This development will be integrating the AP 209 data structure into a larger Product Data Management (PDM) system so that engineering analysis and product design can work with the same data for the end objectives. The EAPM effort utilizes all aspects of the generic data exchange model that PAS-C has been utilizing for Cost and Benefits analysis. The analysis from this project was utilized in the final results that are documented in subsequent sections. The details of the analysis are deemed proprietary and are not included here, but are rolled into the final PAS-C analysis.

3.2.7 Military Products Using Best Commercial/Military Practices (MP-C/MP) Program

The MP-C/MP Program is an Air Force, McDonnell Douglas, and Northrop Grumman Program to reduce costs by changing processes so that best commercial and military processes are utilized in the manufacture of the C-17. The Program consists of several smaller initiatives to address different opportunities for cost reduction. The majority of the following information, except the savings estimates in Section 3.2.7.2, were obtained from the *MP - C/MP INITIATIVE VERIFICATION PLAN for Application Protocol 203, Initiative MI 13, MP-C/MP Program Objectives* [14].

The MI 13 initiative is focused on utilization of AP 203 in lieu of classic hardcopy and proprietary data formats for data exchange. The implementation of AP 203 within Northrop Grumman and McDonnell Douglas is proceeding, but the full implementation would not demonstrate a capability in time to demonstrate the desired capability within the program. Accordingly, efficiencies associated with using AP 203 translators to pass engineering data electronically were validated based upon data collected from the PAS-C Program. The scope of the PAS-C contract is broader than AP 203, in that it addresses efficiencies associated with multiple application protocols and the related import/export translation software. The AP 203 validation focused on results involving use of the AP 203 and AP 209 data models. AP 209 constitutes a superset of AP 203, wherein the MP-C/PM PDM implementation includes documents, parts, assemblies, and files associated with a given engineering drawing as well as the AP 203 data subset. A high level process summary objective from MP-C/PM is given in Table V. This high level process summary is focused on the ability to get the geometric and configuration data (AP 209 and AP 232 respectively) exchanged in a manner that will cut significant labor associated with data re-entry in a prime contractor and sub-contractor relationship.

Table V - Process Summary for MP-C/PM Demonstration

Process for Data Transfer from Prime to Subcontractor			
Activity	Contributors	Data/Systems Involved	Process Functional Goals
Export legacy file of sub-assembly shape envelope into AP 203 format	Prime Contractor	Prime's PDM S/W	Translate legacy CAD/ CAM file format to AP 203 format
Review AP 203 format contents	Prime Contractor	Prime's PDM Software	Verify AP 203 file data content
Send AP 203 data to subcontractor	Prime Contractor	Operating System Utilities	AP 203 file(s) resident on subcontractor's system
Import AP 203 file to legacy PDM format	Subcontractor	Sub's PDM S/W	Translate AP 203 file format to legacy CAD/ CAM format

3.2.7.1 MP-C/MP Program Metrics

The MP-C/PM Program assigned metrics to compare the efficiencies of electronic data transfers to those of a non-electronic transfer which must then be converted to an electronic format. Since the MP-C/PM Program objectives for EDI transfers used existing communications lines, communications costs were not considered. It was assumed that automation costs, associated with processing the data within the competing methodologies, were equal and therefore did not need to be considered. The one-time costs associated with developing the import/export translation software were estimated; these costs would vary somewhat from company to company dependent upon the number of legacy systems to be supported and the quality of the legacy software.

The targeted efficiencies were reduced cycle time and elimination of redundant work. Savings associated with reduced cycle time is somewhat dependent upon the application. Generally, reduced cycle time savings accrue through quicker time to market and reduced inventory costs; e.g., optimization of just-in-time systems, reduction of scrap with engineering change orders, etc. Elimination of redundant work produces a directly auditable savings based upon the procedures eliminated and the salaries of those performing those procedures.

The demonstration metrics/data are:

- Cycle time (per DDE) for EDI transfer from the legacy format of the source company to the legacy format of the destination company,
- Staff hours (per DDE) for error detection and correction quality control (QC) activities (if any) on EDI transfers, and
- Estimated one-time cost of import/export translation software development

The baseline metrics/data requirements are:

- Cycle time (per DDE) for non-electronic transfer from the legacy format of the source company to the legacy format of the destination company
- Staff hours (per item) for manual conversion of data from the legacy system of the prime to that of the subcontractor (break out hours by pay scale)
- Staff hours (per item) for error detection and correction quality control (QC) activities

The MP-C/MP personnel attended the PAS-C demonstration and validated that the data exchange (including the type of data and the potential benefits that can be realized) were valid for an AP 203 implementation scope and that the technology could be utilized on the C-17 Program with similar results. The MP-C/PM personnel will be utilizing this report as the primary source of data input to support the MP-C/PM plan.

The MP-C/MP personnel developed a flow for the use of the PAS-C APs, with AP 203 used for the geometric data, and provided an initial estimate of the usage of AP 203 and the PAS-C APs. This could be further decomposed after the respective functional organizations evaluate the savings opportunities that the PAS-C Program has identified. This flow was used as a basis for the estimates contained in the following section.

3.2.7.2 MP-C/MP Program Metrics Estimates

The MP-C/MP personnel produced a matrix for the PAS-C Team to complete for the metrics. The completed matrices are contained in Tables VI, VII, VIII, and IX. The Tables assume:

- Digital data transfer *communication costs* are equivalent for AS-IS and TO-BE,
- Digital files are generated in Proprietary Format (i.e., Original CAX format) for AS-IS,
- Bulk data transfers (i.e., need index of what files are what data) for AS-IS,
- TO-BE utilizes AP 232 for digital index capabilities,
- TO-BE is AP 203, AP 202, AP 209, and AP 232 only,
- Data being transferred is Product Data TDP and Analysis Data,
- All 'artwork' and 'reference documents' are excluded from analysis,
- Software maintenance costs for CAX application software,
- AS-IS data transfer is between different systems and receiving user has to convert from proprietary original format to target system format,

Table VI - AP 203 - AS-IS METRICS FOR SENDER

Cost of Data Transfers					
Item	Gather Documents For Transfer	Copy Documents (Hard Copy)	Copy Files (Electronic)	Send to Receiver	Other Costs
B.O.M.	1 min per file (digital)	See Note 1	• 1 hour per transfer for job setup • 15 min per tape if postal	• Cost of digital media if sent on media • 1 hour per transfer for packaging/preparation of 1 box of magnetic media	• Shipping List Preparation • Digital Index Preparation
Mylars	See Note 1	See Note 1	Not Applicable	Not Applicable	• Shipping List Preparation
Vector Files (Electronic)	1 min per file (digital)	Not Applicable	• 1 hour per transfer for job setup • 15 min per tape if postal	• Cost of digital media if sent on media • 1 hour per transfer for packaging/ preparation of 1 box of magnetic media	• Digital Index Preparation • Shipping List Preparation
Other Files (Electronic)	1 min per file (digital)	Not Applicable	• 1 hour per transfer for job setup • 15 min per tape if postal	• Cost of digital media if sent on media • 1 hour per transfer for packaging/ preparation of 1 box of magnetic media	• Digital Index Preparation • Shipping List Preparation

NOTES:

1) If original data is in hardcopy format (i.e., mylars, paper) difference in costs for gathering documents for transfer and copying documents has no change between AS-IS and TO-BE analysis. If hardcopy has a digital equivalent, see analysis for Vector Files and Other Files.

2) Assumption that documents for transfer are contained in a single release file or a single repository for sending the data.

3) Assumption that smaller size data shipment (under 10 tapes). Larger size shipment would be scaled accordingly.

4) Digital index preparation is varied based on the configuration management requirements and the data transfer requirements. Therefore, costs are in the 'Other costs' column.

5) Estimates assume that a computer application is able to extract the digital data to tape without additional effort.

6) Estimates identify the applicable tasks that would change

Table VII - AP 203 - AS-IS METRICS FOR RECEIVER

Cost of Data Transfers				
Item	Receive Files and Drawings	Convert to Legacy Format	Check and Validate Data	Other Costs
B.O.M	• 1 hour per transfer for receiving function • 15 min per tape for unload if postal • 1 min per file for DQA against shipping list	• Conversion is a factor of the type of data and if software is available to convert the custom format for BOM - Cost for software development to convert BOM data ($100K min - $1M+ depending on level of complexity) • If digital data conversion, then labor associated with conversion is negligible.	• Typically software to convert the digital data does rudimentary checks to verify data content. • DQA of data in the digital legacy system will run 5-10 minutes per document.	• Training for Originating System Usage (i.e., DQA) • Conversions to legacy format assumes a different System for legacy format.
		• If legacy format is hardcopy, then cost to print a file • If legacy format, and retype the data into another system, the hours per document is a function of the data that is transferred, a full BOM will take 20-40 min a sheet.	• DQA of data that has been re-entered manually is 10-20 min a sheet.	
Mylars	See Note 1	See Note 1 • Rasterization cost runs $1 to $5 per image, depending on level of QA and meta data required for image • Industry average for raster to CAD conversions is 3 hr/sheet	See Note 1 • Industry average for verification of CAD Conversions for DQA is 30 min/sheet	• Reproduction Costs for Distribution
Vector Files (Electronic)	• 1 hour per transfer for receiving function • 15 min per tape for unload if postal • 1 min per file for DQA against shipping list	• Conversion is a factor of the type of data and if software is available to convert the custom format for CAX Applications. IGES conversion costs are primarily cleanup for wireframe and some surface models - Cleanup ranges from 10 min file to 30 min a file. • Conversion for solids models is a lot higher per file. This runs on the order of 1 day a file, depending on the complexity and the ability of the two systems to exchange base geometry for solids data.	• DQA of data in the digital legacy system will run 5-10 minutes per file.	• Training for Originating System Usage (i.e., DQA)
		• If legacy format is hardcopy, then cost to print a file • If legacy format, and retype the data into another system, the best route is to follow the cost associated with mylar information for 2-D data. Surface and solids data conversion was not estimated.		
Other Files (Electronic)	• 1 hour per transfer for receiving function • 15 min per tape for unload if postal • 1 min per file for DQA against shipping list	• This depends on the sending and receiving system ability to exchange data. If from WordPerfect to Word (or vice versa) then cost is 10-20 min per document. Other formats are a sliding scale upward for time.	• DQA of data in the digital legacy system will run 5-10 minutes per file.	• Training for Originating System Usage (i.e., DQA)

Cost of Data Transfers				
Item	Receive Files and Drawings	Convert to Legacy Format	Check and Validate Data	Other Costs

Notes:

1) See previous table assumptions related to hardcopy information.
2) All estimates contained in this table are a function of the quality of the applications that are producing the data and the ability of the receiving system to read the data.

Table VIII - AP 203 - TO-BE METRICS FOR SENDER

Cost of Data Transfers				
Item	Gather Documents For Transfer	Convert from Legacy Format to AP 203	Send to Receiver	Other Costs
B.O.M.	• 2 min per file (digital) to collect and place in secondary repository • See Note 1	• See Note 1 • 5 min per file for conversion. If overnight batch job conversion, then use following number: 1 hour per transfer for job setup • 15 min per tape if postal	• Cost of digital media if sent on media • 1 hour per transfer for packaging/ preparation of 1 box of magnetic media	• Translator Costs ~ $15K initial • Translator Maintenance Costs ~10% of initial • See Note 2 for savings identification areas
Mylars	See Note 1	Not Applicable	Not Applicable	• See Note 1
Vector Files (Electronic)	• 2 min per file (digital) to collect and place in secondary repository	• 5 min per file for conversion. If overnight batch job conversion, then use following number: 1 hour per transfer for job setup • 15 min per tape if postal	• Cost of digital media if sent on media • 1 hour per transfer for packaging/ preparation of 1 box of magnetic media	• See costs above in B.O.M. row, but separate translator for vector files.
Other Files (Electronic)	• 2 min per file (digital) to collect and place in secondary repository	• 5 min per file for conversion. If overnight batch job conversion, then use following number: 1 hour per transfer for job setup • 15 min per tape if postal	• Cost of digital media if sent on media • 1 hour per transfer for packaging/ preparation of 1 box of magnetic media	• See costs above in Vector Files Row

Notes:

1) If original data is in hardcopy format (i.e., mylars, paper) difference in costs for gather documents for transfer and copying documents has no change between AS-IS and TO-BE analysis. If hardcopy has a digital equivalent, see analysis for Vector Files and Other Files.
2) If utilize AP 232 for data transmission, then no cost for digital index preparation. Shipping list costs are also reduced because shipping list will only identify the digital media.
3) Assumption that documents for transfer are contained in a single release file or a single repository for sending the data.
4) Assumption that smaller size data shipment (under 10 tapes). Larger size shipment would be scaled accordingly.
5) Estimates identify the applicable tasks that would change
6) Assumption is that outgoing data has no need for DQA audit. Secondary repository is retained for legal purposes.

Table IX - AP 203 - TO-BE METRICS FOR RECEIVER

Cost of Data Transfers				
Item	Receive Files, Documents, And Drawings	Convert From AP 203 to Legacy Format	Check and Validate Data	Other Costs
B.O.M.	• 1 hour per transfer for receiving and verification function • 15 min per tape for unload if postal	• If batch unload, 15 min per tape.	• Random sampling of data (cost vary based upon level of inspection).	• Translator Costs ~ \$15K • Translator Maintenance Costs ~10% of initial
Mylars	See Note 1	See Note 1	See Note 1	Reproduction Costs for Distribution
Vector Files (Electronic)	• 1 hour per transfer for receiving and verification function • 15 min per tape for unload if postal	• If batch unload, 15 min per tape.	• Random sampling of data (cost vary based upon level of inspection)	• See costs above in B.O.M. row, but separate translator for vector files
Other Files (Electronic)	• 1 hour per transfer for receiving and verification function • 15 min per tape for unload if postal	• If batch unload, 15 min per tape.	• Random sampling of data (cost vary based upon level of inspection)	• See costs above in Vector Files Row

Notes:

1) See previous table assumptions related to hardcopy information.
2) All estimates contained in this table are a function of the quality of the applications that are producing the data and the ability of the receiving system to read the data.
3) Many of the costs above are in minutes alone and are labor time. CPU time would have to be factored from that number.

3.3 Final PAS-C Cost and Benefits Analysis

This section contains the final Cost and Benefits analysis for the PAS-C Program. Due to the nature of cost data, the actual cost of the respective parts that were analyzed are not included for proprietary business reasons.

3.3.1 Methodology for Final Cost and Benefit Analysis

The methodology for the final Cost and Benefit Analysis is documented in **Figure 17**. This methodology was applied to each of the APs that were developed by the PAS-C Program in a manner whereby the level of analysis was dependent upon the level of maturity of the AP development and the maturity of the AP implementations within Industry.

3.3.2 Design to Analysis Application Protocol - AP 209

The design to analysis AP focuses on the data exchange of Finite Element Analysis data between the Design Engineer and the Stress Analyst for static stress analysis. **Figure 29** identifies the nodes from the *Functional Needs IDEF0 Activity and Information Models for the PAS-C Program* (PASC006.01.00) that were considered for the cost analysis.

3.3.2.1 Initial Savings Estimates

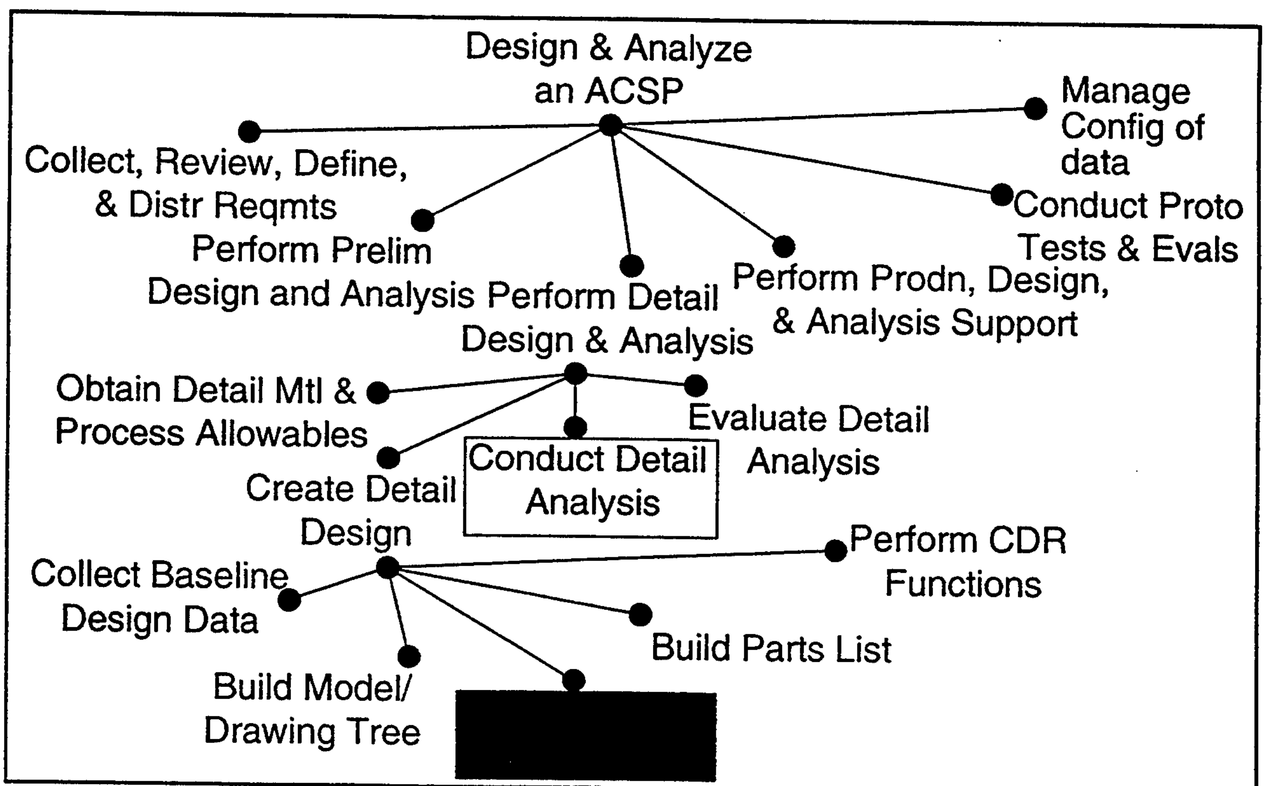

Figure 29 AP 209 Node Tree Benefit Context

Figure 30 identifies the savings based upon the experts analysis of the use of AP 209 in lieu of the current processes that were in place at the time the analysis was completed in 1990-1991.

The labor savings numbers in **Figure 30** were obtained by taking the tasks identified in *Functional Needs IDEF0 Activity and Information Models for the PAS-C Program* (PASC006.01.00) and decomposing the tasks and asking the following question to the experts that developed the activity node tree diagrams:

> "What percent of your time is spent in each of the sub-nodes under an activity node?"

From this question, a determination of where the composite part required the most labor cost could be determined. This was used in quantification of expected benefits in **Figure 30**. The highest level nodes were estimates that varied from company to company. The lower level nodes were evaluated by the experts from that respective area. The node estimates were documented in *Scoping and Benefits Criteria (Volume II) for the PAS-C Program* (PASC008.01.00). It must be kept in mind that since each node decomposition varied from functional area to functional area, the values provided were an indication of where time was spent and did not represent an absolute value when compared between functional areas.

After the percent of time question was documented for the nodes, the experts were posed another question:

> "If your application could receive its inputs in a standard electronic format and your application knew how to read it, then what percent improvement (in labor hours) would you get in each task?"

From this question, a determination of where the composite part required the most labor cost for data input could be determined in relative terms and later quantified. Many functional area personnel felt very uncomfortable giving potential percentage improvements without actually doing the task or going through a more extensive evaluation. Therefore, many functional experts gave an indication of whether or not digital data would decrease their labor requirements. Some experts believed that secondary effects of having digital data would actually increase their labor requirements because the function would be required to do more iterations within the function since it would be easier doing the iterations. These were considered secondary effects by the PAS-C Program, but the functional area experts wanted the secondary, ripple effects taken into account.

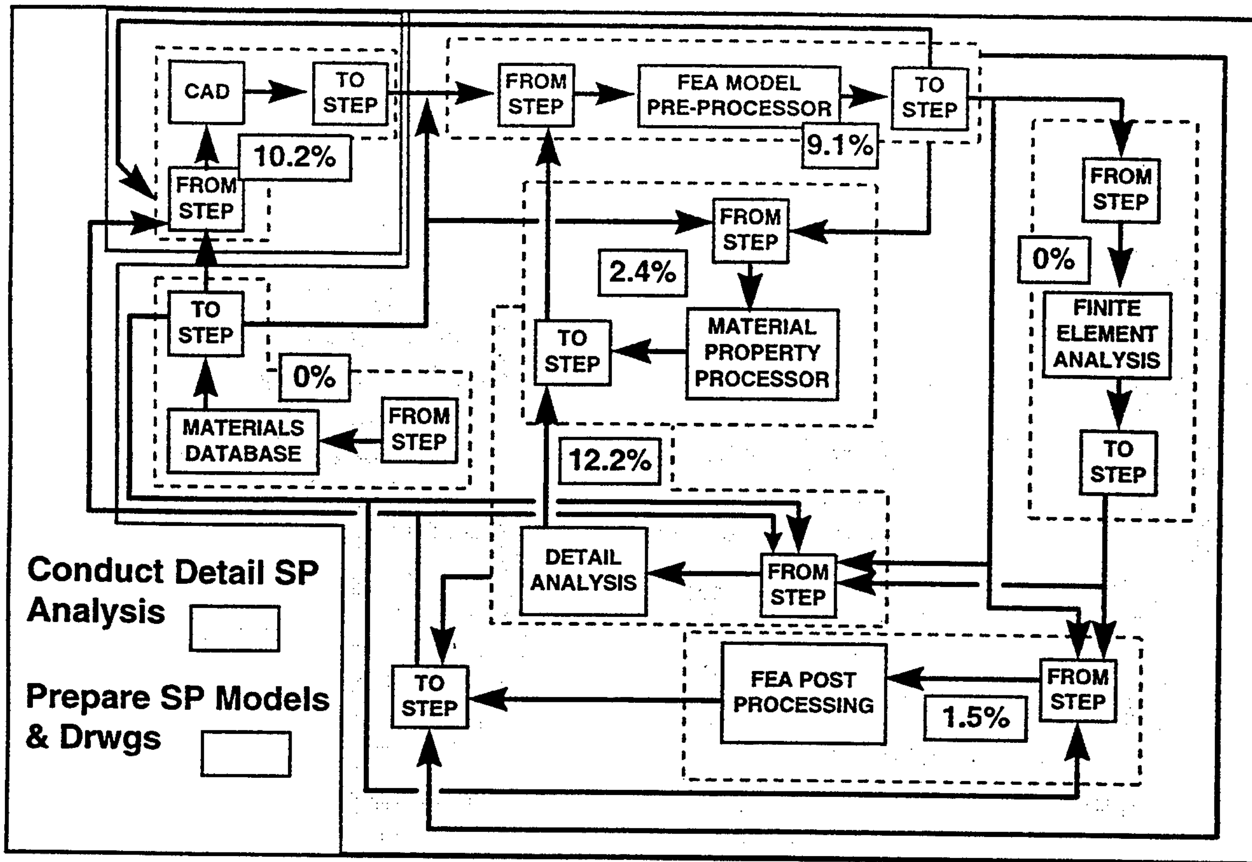

Figure 30 AP 209 Initial Savings Projections

3.3.2.2 Validated Savings Estimates

The participants from the PAS-C, TACOM, and VDE demonstrations/analysis were given the **Figure 30** diagram without any initial savings projections on the diagram and asked to estimate the savings if AP 209 were used for data exchange (in lieu of traditional methods for data exchange) between the applications after the expert had seen the demonstration/approach. The experts wanted to ensure that the non-recurring costs would be identified in any analysis before they would identify what and where the savings would occur. In other words, the identified savings were for labor savings and did not encompass the non-recurring costs which might include:

- **Development cost for AP 209 software applications.** The cost of development of AP 209 software is dependent upon the AP 209 Conformance Class that is implemented and the currently implemented STEP applications. Software development could be one of two alternatives:

  - For an organization that would develop their own AP 209 translator: If AP 203 software applications have already been implemented, then the cost for AP 209 software development is lower because of the AP 209 common use of AP 203

defined geometry and configuration information.

- For an organization that would acquire the AP 209 translators: Considering the state of STEP use within Industry, STEP AP 209 translators should be available for COTS products shortly after AP 209 makes International Standard (IS) status.

In most cases, an organization would develop their own AP 209 translators for internally developed applications that utilize AP 209 data and acquire AP 209 translators whenever a COTS application had one available.

- **Software maintenance costs.** After an AP 209 software appllication is developed or acquired (internally or by a commercial vendor), there is a cost for the maintenance of the software. For internally developed software, this cost would typically be nominal for a period of time, with costs associated with porting the software to different hardware platforms and/or modification to work with newer versions of applications that utilize AP 209 translators. For COTS products, the software maintenance cost may be a percentage of acquisition (typically 10-15% of initial acquisition cost) or on a royalty level (cost per execution).
- **Cost of hardware to run the AP 209 software translation application.** An AP 209 software translation application would typically execute on the same hardware that the data is being translated 'out of' or 'in to'. This hardware is typically a workstation quality (or better) piece of hardware and there would not be additional hardware required.
- **Cost of training.** As with any new software application, there is a cost of training to execute the AP 209 software application. This cost is considered nominal.

The per process savings identified from the experts for the areas that were covered in the respective demonstrations are (these numbers have not been normalized):

FROM STEP -> CAD -> TO STEP from **Figure 30** were 10% for reliability inprovements and 50% for solids data. The solids is a paradigm change from the initial analysis becuase this was not an available option/consideration during 1990-1991 time frame because the technology was not sufficiently developed to handle this type of exchange within an FEA context. The materials is a paradigm change also because the CAX systems did not have a developed capability to represent that matierla is sufficient level of fidelity to be able to adequately represent the materials information within the CAX system.

FROM STEP -> FEA MODEL PRE-PROCESSOR -> TO STEP from **Figure 30** were 10% - 20%. This savings was identified because of the capability to import and export solids geometry and materials for FEA analysis (paradigm change as in previous). Another contributing factor was that the users could more easily switch FEA solvers in and out of the process with an AP 209 format because it was not unique to a NASTRAN or other analysis system. With the ability to represent more complex information, for instance geometric associativities, for an FEA analysis, the FEA solvers have differing capabilities that the expert may want to exploit for a particuliar analysis.

FROM STEP -> FINITIE ELEMENT ANALYSIS -> TO STEP from **Figure 30** were 0% to 20%. The lower number was because there is still not a difference in the process/procedures that were used in some of the application areas. The higher number can be attributed to the ability to switch solvers whenever the need arose (see previous savings paragraph).

FROM STEP -> FEA POST PROCESSING -> TO STEP from **Figure 30** were 0% to 10%. The lower number was because there is still not a difference in the process/procedures that were used in some of the application areas. The higher number can be attributed to the ability to switch solvers and to get the same type of output between the different solvers (see previous savings paragraphs).

FROM STEP -> DETAIL ANALYSIS -> TO STEP from **Figure 30** were 40% to 60%. This higher than expected inprovement was due to several things. First, the tools for detail analysis have improved significantly since the original analysis because of the more widespread use of composites within industry (the original analysis was based primarily on in-house detail analysis software applications utilization). Second, the detail analysis software codes can be written to accept a single input data type for analysis and provide a single output data type for feedback to the designer and/or analyist. In the past, the detail analysis software applications were coupled with a specific FEA solver/FEA post-processor. Third, the ability to obtain standardized output provided a capability to manage the output in a PDM type environment that was not originally possible. This last benefit was not even an option in the original analysis and would provide a new application in **Figure 30**.

FROM STEP -> MATERIALS DATABASE -> TO STEP from **Figure 30** were 10% to 50%. The range of numbers was given because the number depended on the level of complexity of the material parameters available from the matieral DBMS. AP 209 gave the ability to use multiple materials DBMS in lieu of the materials DBMS that was built into the CAX system.

FROM STEP -> MATERIALS PROPERTY PROCESSOR -> TO STEP from **Figure 30** were 60% to 80%. The use of a standardized format between systems allowed an automation of a previously hand and computer process.

The experts appeared to be happy with the quantification of the numbers on a per process basis. The numbers were taken and normalized into the two processes identified in **Figure 29**. The results of the normalization are contained in **Figure 31**. Some of the large savings numbers in the analysis appear to go to minuscule numbers. The reason is that the task, in the context of the entire FEA static stress analysis, is relatively small and is not sufficient justification to commit to an AP 209 standardized format. **When all of the savings taken in combination are added for the entire FEA static stress process, the range is 11% to 48%.** It is noted that, in general, the original estimates appear conservative because the experts did not want to 'bet' on technology development and did not know the different paradigm changes that would occur between the initial and final analysis.

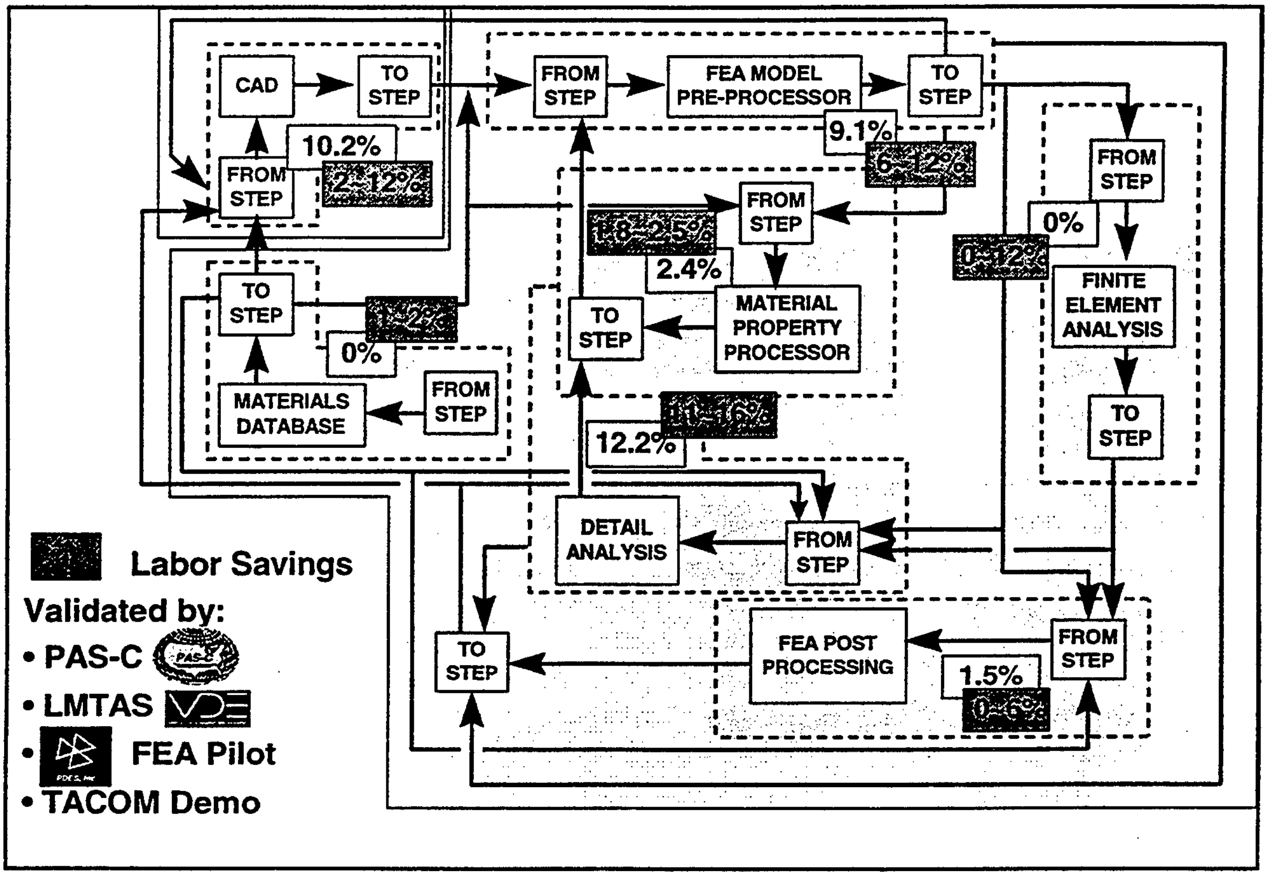

Figure 31 AP 209 Validated Savings from Demonstrations

3.3.3 Design to Manufacturing Application Protocol - AP 222

The design to manufacturing AP focuses on the data exchange of design engineering data between the Design Engineer and the downstream manufacturing processes that utilize that information. **Figure 32** identifies the nodes from the *Functional Needs IDEF0 Activity and Information Models for the PAS-C Program* (PASC006.01.00) that were considered for the cost analysis.

3.3.3.1 Initial Savings Estimates

Figure 33 identifies the projected savings based upon the experts analysis of the use of AP 222 in lieu of the current processes that were in place at the time the analysis was completed in 1990-1991.

The labor savings numbers in **Figure 33** were obtained by taking the tasks identified in *Functional Needs IDEF0 Activity and Information Models for the PAS-C Program* (PASC006.01.00) and following the same process in 3.3.2.1 for decomposing the tasks and asking the experts the same questions for effort expended for the tasks and the savings associated with the task for a standardized input and output.

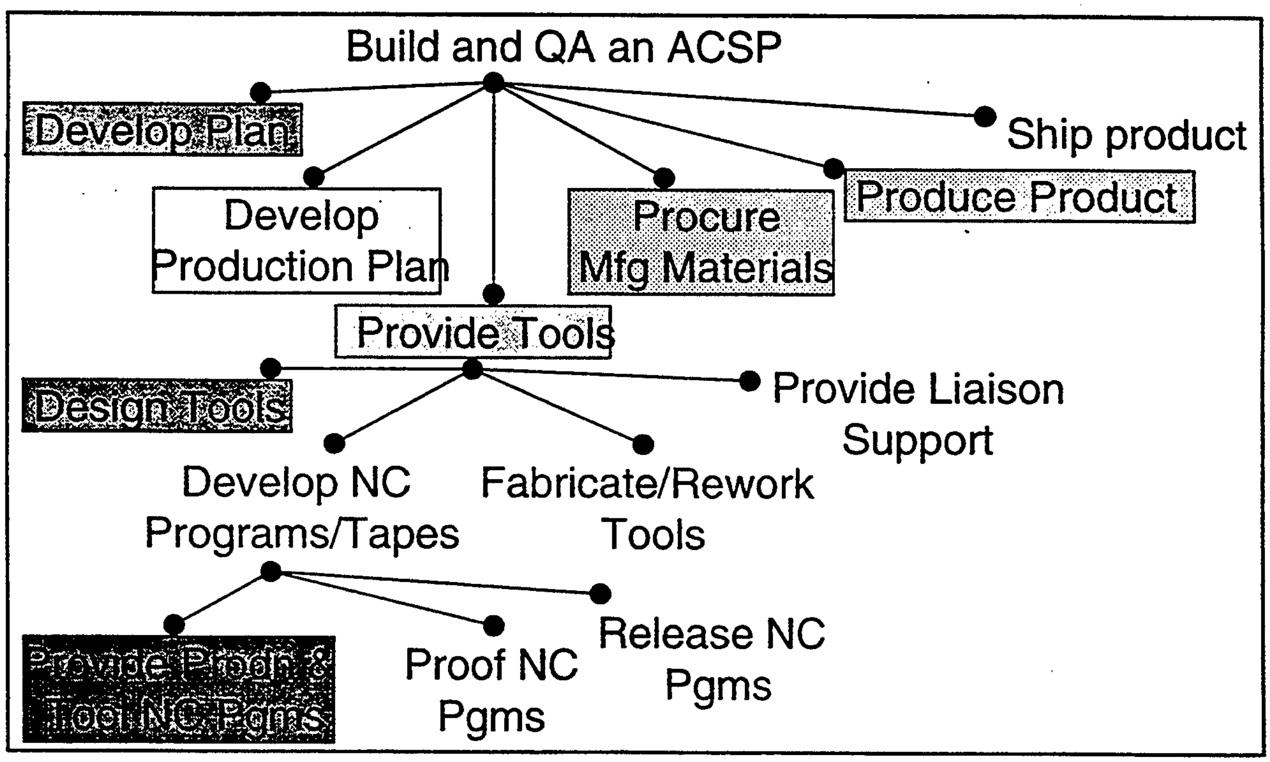

Figure 32 AP 222 Node Tree Benefits Context

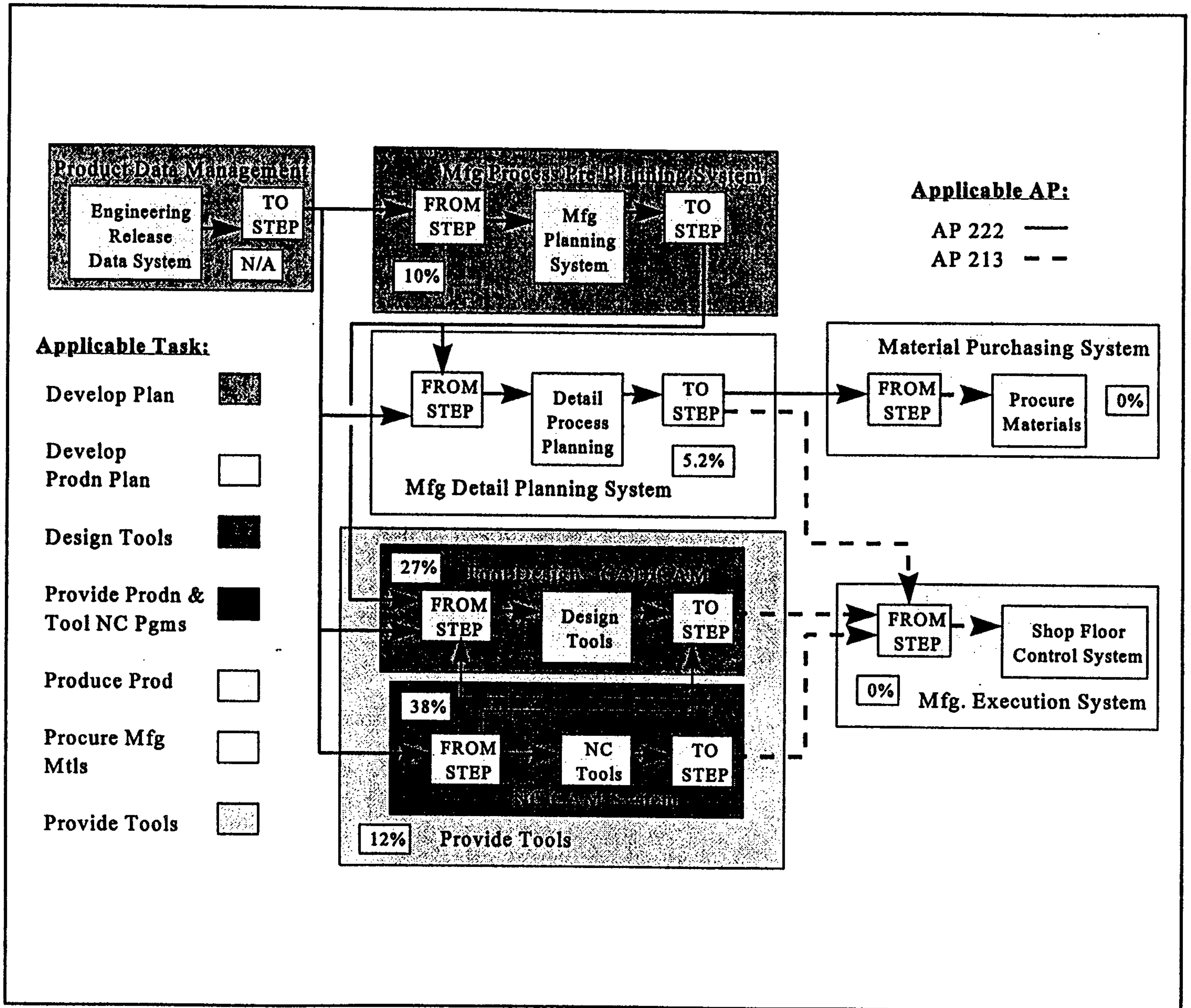

Figure 33 AP 222 Initial Benefits Projections

3.3.3.2 Validated Savings Estimates

AP 222 was not part of any demonstration due to the early stage of development of the AP. Therefore, as part of the Phase III analysis, the PAS-C Team talked to the experts and based upon those discussions, the experts concurred that the initial estimates in **Figure 33** for the PAS-C Program were still valid.

3.3.4 Design to Support Application Protocol - AP 232

The design to support AP focuses on three areas for data representation and exchange:

- data exchange of Technical Data Packages (TDPs) between enterprises in a digital manner,
- configuration information for TDPs within an enterprise that is used in the implementation of a Product Data Management (PDM) system, and
- extension of AP 202 and AP 203 for the representation of classic Parts Lists (PL), Data Lists (DL), Index Lists (IL), Indentured Data Lists (IDL), and Product Data Sets (PDS).

3.3.4.1 Initial Savings Estimates

The initial design to support benefits analysis was conducted based upon PAS-C Team interaction and review of the documentation related to the SPARES Program, the RAMP Program, the ATF Digital Product Models (DPM) Program, the F-22 Digital Product Definition (DPD) Data Program, the EDCARS Program, the FCIM Program, the ATMCS Program, F-16 Program, B-2 Program, B-1 Program, F-111 Program, and the experience that the PAS-C Team brought to the PAS-C Program. Unfortunately, the initial analysis contained in the *Scoping and Benefits Criteria (Volume I - Executive Summary and Overview) for the PAS-C Program* (PASC007.01.00) and the *Scoping and Benefits Criteria (Volume II) for the PAS-C Program* (PASC008.01.00) was not strong because the labor savings for the tasks in the 1990-1991 time frame was not documented well in the information made available to the PAS-C Team. The respective programs did not want to make the savings potential available because savings estimates from previous programs had been utilized inappropriately to reduce the work force. Those work force reductions did not take into account the other factors that PAS-C identified before the reductions were implemented.

3.3.4.2 JEDMICS Analysis

3.3.4.2.1 Background

The Joint Engineering Data Management Information and Control System (JEDMICS) is the Joint Service system for engineering data storage and retrieval. Data from the EDCARS and DSREDS system are being migrated to the JEDMICS System so that a single DoD system can contain all DoD engineering data. The JEDMICS System was originally developed for engineering drawings and related documents that are typically contained in the Engineering Technical Data Package (TDP), but recent efforts have expanded this into other areas for a data repository/vault.

The JEDMICS architecture is comprised of six subsystems: Input, Data Integrity, Index, Storage, Workstation, and Output.

The Input subsystem can accept many types of hardcopy data, including aperture cards, paper, mylar, vellum, and blueline. The Input subsystem can also accept digital data the is IAW MIL-HDBK-59A (and some additional formats): CALS Type I, C.4 Tiled, ASCII, SGML, IGES, CGM, and NIRS/NIFF. Additionally, the Input subsystem can be tailored in a manner whereby different incoming digital formats can be read into the Storage subsystem, as long as the Index subsystem can identify the digital data.

Once the data is within the JEDMICS System, there are several Applications Subsystems that operate on or manage the data: Data Research and Request Subsystem, Security Management Subsystem, File Management Subsystem, Management Reporting Subsystem, and Image Management Subsystem.

3.3.4.2.2 Savings Opportunities

Currently, digital data input to JEDMICS is through a MIL-STD-1840 data entry or through custom software that is a subset of MIL-STD-1840. MIL-STD-1840 is a DoD standard for data transfer between automated data processing (ADP) equipment that is being utilized within the DoD (not very widely used). AP 232 can satisfy the requirements in for data transfer between DoD ADP Systems *AND* AP 232 is a commercial equivalent. The DoD would probably still desire to develop a handbook for peculiarities of DoD developed data, but the availability of COTS applications that support AP 232 would reduce the current costs for data transfer between DoD Systems.

The DoD is striving to use commercial equivalents for DoD standards. AP 232 satisfies that requirement as a possible replacement for MIL-STD-1840 and is still in the early stages of standardization. DoD should take the opportunity to review and comment on AP 232 to ensure that their requirements, JEDMICS in particular, are satisfied.

3.3.4.3 SPARES Analysis

3.3.4.3.1 Background

The initial detailed PAS-C analysis of the SPARES Program is contained in the *Scoping and Benefits Criteria (Volume II) for the PAS-C Program* (PASC008.01.00). The PAS-C analysis of the SPARES program indicated that the SPARES Program was for an initial notion of a system that OO-ALC personnel would use for managing digital TDPs and the related procurement information required for OO-ALC personnel to comply with the government competition requirements and 'limited rights' data. Due to some of the same funding cuts that the PAS-C Program experienced, the SPARES Program modified the scope of the Program to point solutions for different aspects of the personnel involved with the Procurement functions (e.g., Data Screeners).

3.3.4.3.2 Savings Opportunities

The initial SPARES analysis and updates [15,16,17,18] were reviewed and supported the opportunities identified in the initial PAS-C analysis. The statement that the SPARES savings were based upon a neutral standards based data format as initial input to the system is where the PAS-C developed APs and related ISO 10303 APs (i.e., AP 201, AP 202, and AP 203) would be utilized. Without the neutral standards based data as initial input to the system, many of the SPARES savings opportunities may be outweighed by the cost of conversion of the data to a format that could be used directly by the notational SPARES System.

The point solutions that the modified SPARES Program implemented still require digital data, preferably in a neutral standards based format, for the *Master File Repository System*. The same projected savings opportunities for the notation SPARES System and the modified SPARES Program relative to receiving digital data hold true.

3.3.4.4 CMIS Analysis

3.3.4.4.1 Background

The Configuration Management Information System (CMIS) is a Joint DoD system for identification, management, control, and audit of DoD procured systems. The CMIS System has four principle functions that it supports: (1) Configuration Identification (what is the item?); (2) Configuration Control (What changes are approved, in-work, approved, etc.); (3) Configuration Status Accounting (What is the status of physical CIs in the inventory?); and, (4) Configuration Audit (Is the item in compliance with requirements?).

System capabilities related to AP 232 include:

- Interfaces to JEDMICS for TDP documentation (images)
  - CMIS contains most of the same meta-data as JEDMICS
- Functionally equivalent Parts (supplied by different parts vendors)
- Hierarchial Structures for Bills of Materials (BOMs)
  - Part Hierarchy
- Technical Data Packages
  - Document Hierarchy

3.3.4.4.2 Savings Opportunities

A quick review of the application of AP 232 Data Elements to CMIS identified the matches in Table X for CMIS Version 4.0. Although this review was not extensive, it identified the fact that many of the requirements for initial population of the CMIS data structures could be accommodated by AP 232. CMIS capabilities for configuration status accounting of an evolving product (e.g., product in development, product undergoing change, ...) and a deployed product (e.g., where the product is

deployed to, what larger system the product is on, ...) go beyond the intended capabilities of AP 232 to include the business aspects of maintaining the status of the data and/or product as it is used.

Table X - Application of AP 232 Data Elements to CMIS Tables

ENTITY	PAGE	DESCRIPTION
ALTN_PART	C-4	Identifies Alternate Part Numbers, CAGE Codes
BOM	C-8	Equipment/assemblies in parent-to-child relation
CONFIG_VIEW	C-16	Joins several engineering document tables to show revisions, date of revision and nomenclature.
CONFIG_VIEW 2	C-17	Joins multiple tables to complete document breakdown and inverted tree.
DOC	C-22	A table of engineering drawings, specifications standards. technical manuals and other documents.
DOC_ASSOC	C-23	Table of parts lists, wire lists associated with engineering drawings.
DOC_ASSOC-IMAGE	C-24	An index of raster images of documents associated with other documents.
DOC_IMAGE	C-27	An index of raster images of engineering drawings.
DOC_PART	C-28	Relates Engineering Drawings to Manufacturer Part Numbers.
DOC_SHEET	C-30	Identifies multiple sheets of an engineering drawings.
ECP_DOC	C-37	Identifies all documents affected by an ECP.
ECP_IMAGE	C-38	Index of raster images of attachments to an ECP.
ECP_INFO	C-39	Information on areas impacted by an ECP.
ECP_PART	C-44	Identifies all parts affected by an ECP.
PART	C-64	A table which identifies manufacturers part numbers, CAGE code and description

It is perceived that the long term integration of DoD Systems will include the merging and/or seamless combination of the JEDMICS and CMIS for a single view of the product data by the DoD user. AP 232 could be the format of the data that is used for the initial population of the data into this system and/or as the data format for exchange of the product data and document data in a digital environment.

3.3.4.5 Logistics Support Analysis

3.3.4.5.1 Background

The Logisitics Support Analysis (LSA) process is completed by prime and sub-contractors to establish the logistic support requirements for a system. This process is documented primarily in the Logistics Support Analysis Record (LSAR). The LSAR is a data base containing the documentation of the analysis. In recent years, the documentation is a relational database that is a series of interrelated tables of support information used by the Air Logistics Centers and USAF Item Managers for life cycle support of the weapon system. The LSAR is established by support analysts reviewing design documents and completing inputs into the various LSA tables. This process is very labor intensive and requires several years to complete. The complete LSAR contains 518 Data Element Descriptions (DED). The Packaging and Provisioning Process, which completes the 'H' tables of the LSAR, use the Engineering Design File as their primary source document to create a top-down parts breakdown of the complete weapons system. The provision files are then transmitted to the ALC via magnetic tape for input into the D-220 spares management system. The LSAR 'H' records are accompanied by Provisioning Technical Documentation (PTD) which consists of two hard copies of engineering drawings, parts lists and general notes. The initial provisioning file is submitted with delivery of the first aircraft or end item and must be up-dated with every Class 1 design change through out the operational life of the weapon system. The application of AP 232 to the LSAR would offer significant reduction in process time for the initial creation and future up-date of the Packaging and Provision Data. Appendix B contains the IDEF ICOM decomposition for the analysis of the application of AP 232 to the Logistics Support arena.

3.3.4.5.2 Savings Opportunities

The provisioning data contained in Packaging and Provisioning Data file is created in 15 tables of the 'H' Record of the LSAR. A flow chart of the H Tables and their relationship to other LSAR record is shown in **Figure 34**. A review of the data identification descriptions contained in Appendix A of MIL-STD-1388-2B reveals 70 entries which could be electronically entered from the Engineering Design File by use of AP 232. Identification of individual entries by MIL-STD-1388-2B Table is shown in Table XI.

MIL-STD-1388-2B
APPENDIX A

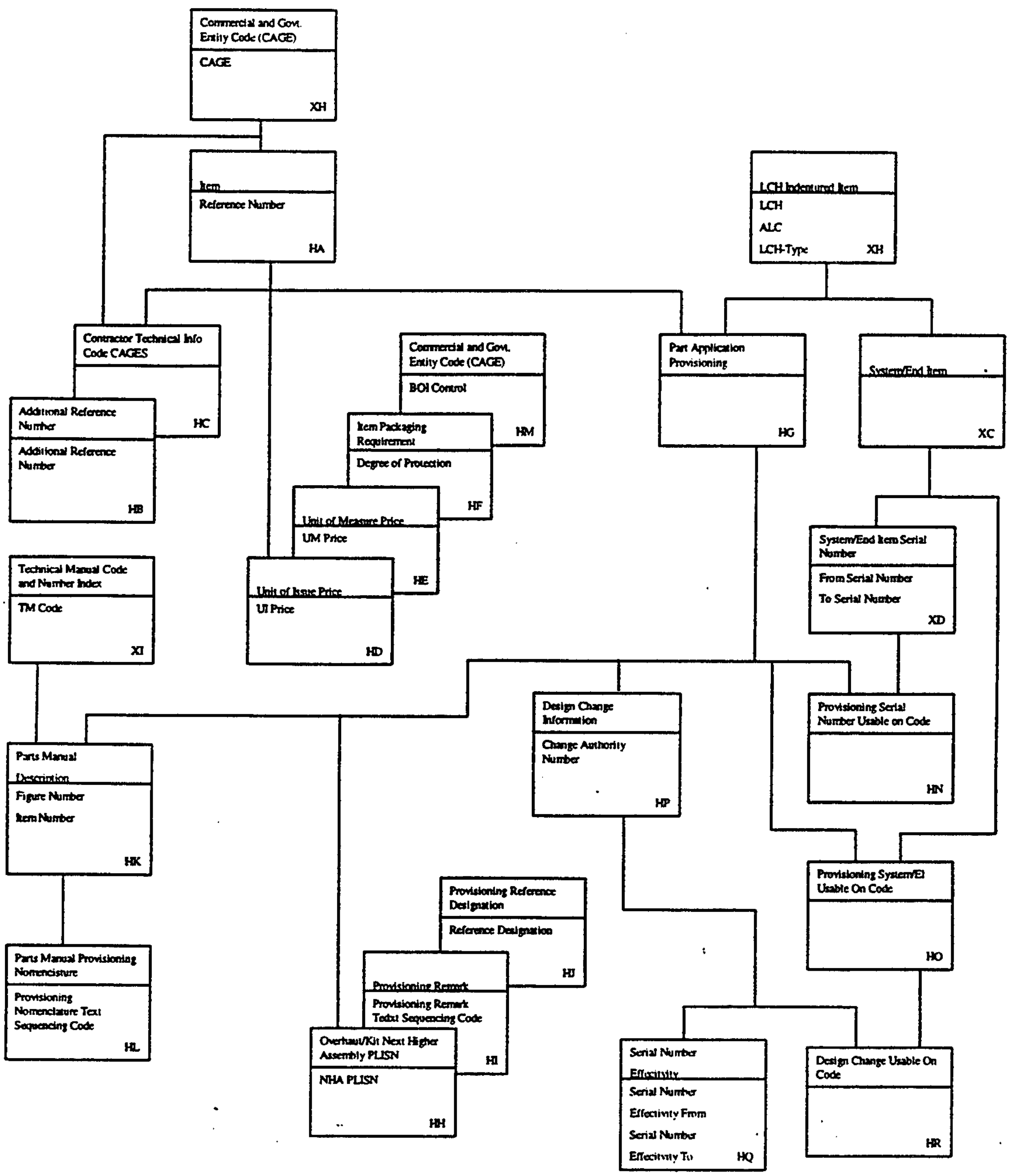

FIGURE 12. H TABLE RELATIONSHIPS.

Figure 34 MIL-STD-1388-2B 'H' Table Relationships

Table XI - Engineering Drawing Data Transferred to LSAR 'H' Tables

TABLE/ ELEMENT	DATA ELEMENT TITLE
HA	18 Entries
DED 046	Cage Code
DED 337	Reference Number
DED 182	Item Name
DED 086	Document Availability Code
DED 395	Special Material Content Code
DED 392	Special Maintenance Item Code
DED 066	Criticality Code
DED 293	Precious Metal Indicator Code
DED 003	Acquisition Method Code
DED 497	Unit Weight
DED 496	Unit Size Length
DED 496	Unit Size Width
DED 496	Unit Size Weight
DED 337	Reference Number
DED 154	Hazardous Code
DED 491	Unit of Measure
DED 065	Critical Item Code
DED 220	Material Weight
DED 218	Material

TABLE/ ELEMENT	DATA ELEMENT TITLE
HB	6 Entries
DED 046	Item Cage Code
DED 337	Item Reference Number
DED 046	Cage Code
DED 006	Additional Reference Number
DED 338	Reference Number Category Code
DED 339	Reference Number Variation Code
HC	2 Entries
DED 337	Item Reference Number
DED 046	CTIC Cage Code
HD	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HE	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HF	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HG	8 Entries
DED 046	Cage Code
DED 337	Reference Number
DED 316	Quantity Per Assembly
DED 070	Data Status Code
DED 162	Indenture Code

TABLE/ ELEMENT	DATA ELEMENT TITLE
DED 317	Quantity Per End Item
DED 151	Hardness Critical Item
DED 177	Item Category Code
HH	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HI	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HJ	4 Entries
DED 046	Cage Code
DED 377	Reference Number
DED 335	Reference Designation
DED 336	Reference Designation Code
HK	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HL	2 Entries
DED 046	Cage Code
DED 337	Reference Number
HM	2 Entries
DED 046	Cage Code
DED 337	Reference Number

TABLE/ ELEMENT	DATA ELEMENT TITLE
HN	2 Entries
DED 046	Provisioning Cage Code
DED 377	Provisioning Reference Number
HO	2 Entries
DED 046	UOC Provisioning Cage Code
DED 337	UOC Provisioning Reference Number
HP	4 Entries
DED 046	Cage Code
DED 337	Reference Number
DED 043	Change Authority Number
DED 172	Interchangeability Code
HQ	5 Entries
DED 046	Cage Code
DED 337	Reference Number
DED 043	Change Authority Number
DED 374	From Serial Number Effectively
DED 374	To Serial Number Effectively
HR	3 Entries
DED 046	UOC Provisioning Cage Code
DED 337	UOC Provisioning Reference Number
DED 043	Change Authority Number
TOTAL	70 ENTRIES

An LSAR Data Transfer Utility could be configured to read in AP 232 data for establishing the 70 entries of Part Number related data in the Packaging and Provisioning records. Use of a direct electronic transfer would permit much faster analysis of drawing revisions for impact on spares and

repair parts. Actions needed to revise future procurement, stop on-going repair lines and notify operating units could be accomplished in a more timely manner. Use of the AP 232 data by EDCARS/JEDMICS would facilitate the migration of data to the Packaging and Provisioning files. In addition, data from H tables HK and HL could transfer the revised part number data to the Technical Manuals Department for use in revision of the Illustrated Parts Manuals.

A new LMI performance specification is in the release process to replace MIL-STD-1388-2B. The new specification defines requirements for Supportability Analysis Summaries (SAS) which bear some similarities to the reports contained in MIL-STD-1388-2B. The two functional areas of Supply Support and Support Equipment still require contractor data for use by government in-house systems. Appendix B of the LMI specification will provide data for input into provisioning systems. In the meantime most contracts currently in effect still require delivery of MIL-STD-1388-2B LSAR data. It is reasonable to expect that AP-232 could be used for electronic transfer of the LMI data and aid in the transition from the LSAR databases.

3.3.4.6 Program Parts Selection List

3.3.4.6.1 Background

Many DoD Weapon System Programs have a requirement to use of as many DoD standard parts as possible. This requirement is driven by the DoD need to minimize stocking a wide variety of very similar parts for different DoD Weapon Systems (or in some cases very similar parts for a single weapon system that is being built by several hundred subcontractors). Therefore, the DoD mandates a set of standard parts for each DoD Weapon System through a document called the 'Program Parts Selection List' or PPSL. This is usually a tab run of the current DoD NSN numbers that are used by the DoD/DLA for support of current Weapon Systems. The prime contractor on a new program has to ask for an exception for each new part that is designed or used on the new program that is not on the PPSL. This is to ensure that duplicate parts and/or very similar parts with the same functionality do not proliferate within the DoD infrastructure.

3.3.4.6.2 Savings Opportunities

The opportunities for applying PAS-C developed APs to the PPSL process were reviewed and the DDE capability for simple lists of parts/documents was found to be able to satisfy the PPSL data exchange requirements. If AP 232 was utilized in this role, then the PPSL could be transferred between the government, prime contractor, and sub-contractor in a digital environment. Then applications like the PAS-C demonstrated DDE viewer (i.e., HTML viewer) could be utilized to interrogate the PPSL and do 'find's on part numbers, part names, CAGE codes, etc. This would eliminate the manual labor required for data re-entry by the prime contractor and sub-contractor community and provide a ready tool for the end user to search the PPSL for the information that they need.

The DDE also provides a capability to classify parts into part families so that the parts could be classified by the type of part, usage, weight, etc. In this manner the prime contractor and sub-contractor community could reduce costs associated with the search and research required by the prime and sub-contracting community.

3.3.4.7 Product Data Management Systems Analysis

3.3.4.7.1 Background

Product Data Management (PDM) Systems are being widely implemented within Industry today. As described in other sections, PDM Systems typically require fairly extensive customization as part of implementation. This is because the PDM Systems are implemented to match existing company processes and terminology used within the company. Within the larger companies, PDM Systems are being used for:

- Teaming/Data Exchange - Different programs within a company are implementing PDM Systems for data access and/or data mirroring between different program sites. With some of the larger Programs where multiple companies are involved, the companies are attempting to utilize PDM Systems to manage the data the program users have access to. In this manner, the users will have the most up to date information available. One of the issues related to this is that one PDM System does not necessarily store the data in a format that the different sites/companies can directly utilize. Thus, there is a need for a neutral data exchange standard.
- Data Archive/Data Migration - In many companies, the engineering data that is developed for the manufacture of the product is utilized for several years (and in some cases for several decades). Applications that were utilized to develop/retrieve the data become obsolete and/or are not upward compatible. A PDM implementation stores the data as a bit bucket and needs to have a neutral standards format for subsequent data access so that the data does not become un-usable.
- Data Sharing/Tool Interoperabillity - PDM Systems store the data files as a bit bucket and the PDM System stores the meta-data about the data files (e.g., file format, relationship of the part contained in the file to other parts in other files). In many cases the file information is in a proprietary format and is only usable by that particular application.

3.3.4.7.2 Savings Opportunities

The savings opportunities for AP 232 (and for the other PAS-C developed APs) is enormous in the PDM Systems area. Specifically,

- **Teaming/Data Exchange** - A meta-data structure based upon AP 232 will allow different programs within a company to implement PDM Systems for data access and/or data mirroring between different program sites with little or no re-work associated with exchange of data between the sites. When larger programs (where multiple companies are involved)

utilize a PDM System and if the companies base their PDM implementation on a AP 232 structure, the data exchange between the companies would require little or no re-work to exchange the data. Any of the PAS-C developed APs could be used as the data format of the files in the PDM System.

- **Data Archive/Data Migration** - As in the previous item, any of the neutral standards based APs that were developed by PAS-C (or for that matter, any of the ISO 10303 APs) Program could be utilized for data archive and/or data migration because the end user has access to the data format for extraction (unlike proprietary formats). Tools that are leading edge one day may become obsolete in a few years - the data associated with that tool also becomes obsolete if the data is not accessible in a neutral standards based format.
- **Data Sharing/Tool Interoperabillity** - PDM Systems store the data files as a bit bucket. Interchangeability of tools in the utilization of the data is essential to remain competitive in today's environment. A neutral standards based format is the best method for achieving this goal.

3.3.4.8 Internet/Intranet Analysis

3.3.4.8.1 Background

As described in Section 3.1.2, the Internet and the Intranet are playing a larger and larger role in the daily lives of the average American as well as the average engineer. The Intranet is being more and more widely used for access to data and information on a global basis. Many commercial companies are using the Internet for advertising their products and providing catalog information on their products. This media provides standard part suppliers, as well as custom design businesses, an opportunity to advertise and make available their product to a broader market with little or no additional cost.

The Intranet use within companies and organizations is broadening because of the ready access to data in a format that is compatible with HTML browsers. The usage is for company access to standard part data, data/drawing viewers, release information and status, etc.

3.3.4.8.2 Savings Opportunities

AP 232 through the PAS-C demonstrations proved the concept that data access through HTML viewers is viable and usable through fairly inexpensive products (e.g., Netscape). The data structures within AP 232 for top down breakdown (i.e., part, document, or mixed) and file information for the top down breakdown is defined for that capability to be exercised. AP 232 also provides the data structures to provide catalog information for products with part family/part classification information. A populated AP 232 data file provides a capability, when the instantiated data is converted to HTML format, to provide users relatively inexpensive access to data without expensive CAX applications. HTML does not provide data structures for a data model, but provides an ability to relate different 'existing' data together. HTML is not a data modeling language.

The savings opportunities are enormous for an implementation of AP 232. AP 232 data can be used by many organizations to 'find' information related to their product and/or products of other organizations/companies. AP 232 can be a basis for developing the HTML applications for data access. AP 232 provides the data model that the data would be populated into for an HTML application to access.

3.3.5 Part Cost Analysis

The *Scoping and Benefits Criteria (Volume II) for the PAS-C Program* (PASC008.01.00) identified costs and potential LCC cost savings for the selected parts based upon manhours per part is shown in Table XII for the entire PAS-C Application Protocol Suite (AS). These results were formulated by running each selected part through the LCC analysis and evaluating each of the application protocols (Design to Analysis, Design to Manufacturing, and Design to Support). The values in Table XII reflect the summation of the LCC analysis results from each of the three application protocols when only their highest payback data exchange scenario was considered. The three parts were a Contoured Skin Laminate (CSL), Core Stiffened Panel (CSP), and "T"-Composite Assembly (TCA). The value represents labor hours to perform the life-cycle tasks. The table shows the hours it takes today (AS-IS) to perform the tasks and the hours it was estimated to take when the application protocols are implemented (TO-BE).

Table XII - Part Costs (Man-hour) from Initial Part Evaluation

DEMO PART	PAS-C AP SUITE (MAN-HOURS)			
	AS-IS	TO-BE	Δ HOURS	REDUCTION
CSL	2184	1811	373	17%
CSP	4401	3623	778	18%
TCA	660	556	104	16%

Using an average aerospace burdened engineering labor rate for 1995 and applying this to Table XII, the dollar values in Table XIII were obtained.

Table XIII - Part Costs (Dollars) from Initial Part Evaluation

DEMO PART	PAS-C AP SUITE ($ FOR MH)			
	AS-IS	TO-BE	Δ DOLLARS	REDUCTION
CSL	$230K	$190K	$40K	17%
CSP	$460K	$380K	$82K	18%
TCA	$70K	$58K	$11K	16%

Not all of the costs in Table XIII are engineering hours, but this dollar value was used to cover the costs related to departmental costs for Manufacturing Engineers, Tool Designers, Process Planners, and/or NC Programmers equipment.

When the original hours from Table XII are broken out for AP 209 usage and correlated with the savings identified in Figure 31, the range of savings available from AP 209 implementations are given in Table XIV for man-hour savings and Table XV for dollar savings related to the man-hour savings.

Table XIV - AP 209 Part Costs (Man-hours) Savings Range

DEMO PART	PAS-C AP 209 Savings			
	AS-IS	TO-BE	Δ HOURS	REDUCTION
CSL	1512	1346-786	166-726	11-48%
CSP	2721	2422-1415	299-1306	11-48%
TCA	36	32-19	4-17	11-48%

Table XV - AP 209 Part Costs (Dollars) Savings Range

DEMO PART	PAS-C AP 209 Savings			
	AS-IS	TO-BE	Δ DOLLARS	REDUCTION
CSL	$160K	$145K-$85K	$17K-$76K	11-48%
CSP	$290K	$255K-$150K	$32K-$137K	11-48%
TCA	$4K	$3K-$2K	Negligible	11-48%

Savings estimates for the other APs were not deemed appropriate because the initial savings estimates were documented in the original analysis and no validation was done on those APs in the demonstrations.

Use of the cost and savings numbers in this section need to be made with caution because they represent labor savings and do not factor the cost of hardware, software, training, and other related costs into the savings estimates. See prior sections related to what is included and what is not included in the savings estimates.

4 SUCCESS CRITERIA

The PAS-C Program success criteria were originally defined in the *Scoping and Benefits (Volume 1) for the PAS-C Program* (PASC007.01.00). These criteria were derived from the Air Force's program objectives and reviews with the Air Force Program Manger. The purpose of the criteria were to establish measurable criteria that would help to guide and prioritize PAS-C tasks and deliverables over the duration of the PAS-C Program. Table XVI is the original criteria with the last column containing the achievements of the PAS-C Team for that criteria. All the Success Criteria that were defined for the PAS-C Program were satisfied.

Table XVI Program Objectives & Success Criteria

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA		
MAJOR OBJECTIVES	**SUCCESS CRITERIA**	**CRITERIA MEASURE**
1 Develop a product definition information model sufficient to represent and exchange information to design, analyze, test, produce, assure the quality of, and repair composite parts as typified by aircraft composite structural components.	**A** How many of the functional areas (e.g., design) did the program address?	The PAS-C SOW stated that the PAS-C Program would 'develop and demonstrate a product definition information model sufficient to represent and exchange information to design, analyze, test, produce, assure the quality of, and repair composite parts as typified by aircraft composite structural components.' Phase I of the PAS-C Program developed and analyzed the current ACSP requirements in several CDRLs and compared this against the current PDES/STEP SOTA to identify where the standard was applicable and where the most benefit (with the PAS-C Program resources) could be obtained. Of the six areas identified in the SOW, PAS-C directly addressed 'design', 'analysis', and 'produce' areas with APs. The 'test', 'assure the quality of' and 'repair' areas were also addressed with the ability to use the PAS-C APs where applicable in these areas.
	B How well did the information model support the needs of the addressed functional areas? This should be measured by the completeness of the data to fully satisfy the requirements of Level 3 production drawing packages as specified in MIL-T-31000.	**Information functional needs:** ● AP 209 directly addressed all FEA static stress analysis for composites and homogenous materials with STEP AP developments. It could be used for other FEA analysis (e.g., dynamic, thermal). ● AP 222 directly addressed Manufacturing Process Planning development (production and detail level), NC Development (geometry, part identification), Bill of Material (engineering and manufacturing), Shape, and Tolerance information needs with STEP AP developments. ● AP 232 directly addressed design, manufacturing, configuration control, data management, and support data requirements with STEP AP developments. This included the capability to manage and control other digital formats beyond STEP. **Level 3 Production Drawing Packages:** ● AP 232 directly extends the drawing capability of AP 201 and AP 202 for associated lists defined in DOD-STD-100 and ANSI Y14. ● AP 232 can exchange full MIL-T-31000 data packages. This includes identification of full digital MIL-T-31000 TDP data elements and hardcopy MIL-T-31000 requirements. AP 232 enhances the delivery of MIL-T-31000 data exchanges with the capability to provide top down breakdwon of the TDP data elements.

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA

MAJOR OBJECTIVES	SUCCESS CRITERIA	CRITERIA MEASURE
	C How well and how many typical aircraft composite structural parts does the information model cover?	The PAS-C Phase I analysis identified where the high payback areas for ACSP were and focused on the development of the information model to satisfy those needs for the high payback areas. AP 209 is applicable to metallic and composite parts. Within this arena, only fiber wound composite parts are known to be a potential area that AP 209 and AP 222 do not support. AP 232 is applicable to all part definitions, electrical or mechanical. No known deficiencies have been identified.
2 Demonstrate a product definition information model sufficient to represent and exchange information to design, analyze, test, produce, assure the quality of, and repair composite parts as typified by aircraft composite structural components.	**A** How well does the demonstration show the extent/completeness of the information model?	• The demonstration level of ARM and AIM coverage is documented in Table III for all demonstrations of AP 209. • AP 232 capabilities related to the exchange of TDPs was demonstrated at the highest level. AP 232 capabilities for Associated Lists was not tested in the demonstration, although many of the data elements used for development of the exchange of TDPs was the underlying foundation for the exchange of TDPs. • The demonstration level of ARM and AIM coverage is documented in Table IV for the PAS-C demonstration of AP 232. • AP 222 was not addressed in any of the demonstrations due to the stage of development of the data model.
	B How well does the demonstration show implementation opportunities? (Could be measured by the number of vendors on the Vendor Implementation Group (VIG) and to the number of vendor who participate in the demonstration itself and their level of participation)	• In leveraging efforts, the VIG effort was taken over by the PDES, Inc. Vendor Round Table for a broader STEP purview. PAS-C members participated in the Round Table efforts and have been instrumental in the direction that the Round Table has taken toward implementations. The mature PAS-C APs are ranked within the priorities for vendor implementation. • For the mature PAS-C APs, vendors have been active in the review and the feedback on the AP content, scope, and implementation issues. • ISS (InSync), MSC (PATRAN), Unigraphics (UGII), Dassault (CATIA), Netscape, and ITI (STEP Works, and Geometry Visualizer) have products that were used in the final demonstration. MSC, ISS, and ITI have provided resources to the PAS-C program to accomplish these ends. • Vendors have embraced the PAS-C APs and have committed commercial software development efforts to implement the mature PAS-C APs.

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA

MAJOR OBJECTIVES	SUCCESS CRITERIA	CRITERIA MEASURE
	C How clear is the rational for potential cost benefit documented?	• The preliminary and final cost analysis were well documented. The cost information was 'scrubbed' to protect proprietary data. • The TACOM, FEA Pilot, and PAS-C demonstrations validated the cost numbers for recurring costs.
3 Initiate and establish the procedures required to provide a neutral data format for composite structures so that the composite product data can be digitally transferred between industry producers and also between these producers and government agencies.	**A** How many different implementation scenarios do the developed APs support?	This document identifies the different implementation scenarios that were tested within PAS-C and by other demonstrations.
	B How well are these scenarios documented? (Could be measured by completeness/ useability of the AP users guide and the confidence the Air Force shows by the initiation of these data delivery requirements in their weapon systems contracts.)	Reference documentation is identified in Section 3.2 for all demonstrations.
	C Do the APs cover transfer between industry partners?	The APs were developed within the International Standards Community where all factions of industry are participating. These factions are mostly concerned with data exchange between industry partners and made heavy contributions which were incorporated into the PAS-C efforts.
	D Do the APs cover transfer between industry and government agencies?	•AP 232 directly addressed the data exchange between Industry and Government agencies for data exchange related to a TDP. • AP 209 data is not typically exchanged between Industry and Government, but AP 209 is an enabler to allow this to happen.
	E How well do the APs support Integrated Product Development?	• Standards based digital data exchange is an enabler for IPD: • Teams can work at different locations and in different areas of a company without having to centrally locate for data access. • Digital data exchange promotes the capability for 'Create data once and use it several times' philosophy.
	F How well do the APs support reduced product delivery time?	• Most of the quantifiable benefits are related to reduced turn around times and reduction in repetitive data entry tasks. This was one of the guiding factors in the original scoping and benefits analysis. • The other sections of this final report identify quantified and qualified measures of the support that the AP provides.
	G Where and how do these APs reduce the cost of Air Force weapon systems?	See Section 3 of the PAS-C Final Technical Report and Cost/Benefits Analysis.

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA

MAJOR OBJECTIVES	SUCCESS CRITERIA	CRITERIA MEASURE
4 Define the framework for application specific implementation procedures to be used in making the Product Data Exchange using STEP (PDES) specification supportive of the full spectrum of manufactured parts and procedures throughout their product life-cycle.	A Was a framework methodology/procedure developed?	Yes. The original proposal identified the methodology and the functional needs document was based upon the PAS-C framework/building block approach.
	B How successful was this methodology in developing the AS?	The functional needs document was utilized in the development of the potential scenarios for utilization of the technology and where to focus the PAS-C development efforts. A software application was developed that integrated the framework building block approach with the data utilization concepts to provide any view of the data from any perspective.
	C Is the methodology extendable to other manufactured parts? If so, to what extent?(what product types and life-cycle functions?)	• The methodology was utilized/extended by PDES, Inc to identify the technical direction of the consortium and inter-relationships between the different views (e.g., commodity vs life cycle view) of product data that were to be addressed by the consortium. • The APs that have been developed under the auspices of PDES, Inc have utilized this methodology to develop, refine, and analyze their requirements.
	D How well is this methodology documented? (Were pit-falls identified and recommended changes documented?)	The methodology is documented in several PAS-C documents and is documented explicitly for AP 232 [19].
	E How easy is this methodology to use?	The methodology is quite simple and graphically based to help to identify data relationships and data-inter-relationships. After somebody becomes familiar with the methodology, the approach is quite natural. The utilization of the methodology by an industry consortium and other AP developers is testament to its ability.
	F Have any other projects/organizations used this methodology or any portion of the methodology?	• The methodology was utilized/extended by PDES, Inc to identify the technical direction of the consortium and inter-relationships between the different views (e.g., commodity vs life cycle view) of product data that were to be addressed by the consortium. •The APs that have been developed under the auspices of PDES, Inc have utilized this methodology to develop, refine, and analyze their requirements.

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA

MAJOR OBJECTIVES	SUCCESS CRITERIA	CRITERIA MEASURE
	G Has any of this methodology been incorporated into STEP?	• Not directly as part of the development of the STEP standard. Many STEP APs have used the methodology to identify three data needs for their particular AP development. • WG 10 is currently evaluating a Framework for the STEP standard. Specifically, AP interoperability for the long term health of the STEP standard. There are many different approaches on the table, each with there own merit. The PAS-C Framework/Building Block approach is one of the approaches being seriously evaluated.
5 Promote the growth and maturation of PDES and endorse its use as a national standard.	A How many committees did the PAS-C support? (chair, members of)	• PAS-C has directly supported three IGES/PDES Organization Chairmen: 1) Finite Element, 2) Manufacturing Technology, and 3) Composites. • PAS-C has directly supported two International Organization for Standardization TC184/SC4/WG3 Team Leaders: 1) Finite Element, and 2) Manufacturing Technology. • As Chairmen/Team Leaders of the above, the PAS-C Program has heavily influenced the direction of the standard. • The PAS-C Team has been active in most of the other committees because of the development of the PAS-C APs.

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA

MAJOR OBJECTIVES	SUCCESS CRITERIA	CRITERIA MEASURE
	B How many STEP models did the AS enhance through use of the part?	• The PAS-C Team Members have been owners of the following models: ISO 10303-49 - Process Structure and Properties, ISO 10303-104 - Finite Element, ISO 10303-209 -Composite and metallic structural analysis and related design, ISO 10303-222 - Composites Manufacturing, and ISO 10303-232 - Technical Data Packaging Core Information and Exchange. • Most of the Generic Resource (40 series) Parts have been influenced by the PAS-C development due to the nature and evolving capabilities of the STEP standard. • ISO 10303-209 has directly extended capabilities defined in ISO 10303-203 (FEA capability, composites). • ISO 10303-232 has directly extended capabilities defined in ISO 10303-201 (associated lists), ISO 10303-202 (associated lists), and ISO 10303-203 (documents, product data sets). • ISO 10303-222 has directly extended capabilities in ISO 10303-203 (tolerances, manufacturing planning, composites).

PAS-C PROGRAM OBJECTIVES & SUCCESS CRITERIA

MAJOR OBJECTIVES	SUCCESS CRITERIA	CRITERIA MEASURE
	C What type of technology transfer was accomplished? (IPO, ISO, other standards organizations, hardware/software vendor community, composite manufacturing community, potential PDES user community, government agencies, synergism between other on-going programs)	PAS-C has leveraged/been leveraged by the following programs: NIST CALS TDP Program, PDES, Inc. Interoperability Team, PDES, Inc FEA Pilot, TACOM Pilot, IPO Organization, ISO TC184/SC4 Organization, Supplemental Directives Development, AP Interoperability Team, Measures Team, SEDS Team, ISO 10303-41 DAM Team, ISO 10303-44 DAM Team, ISO 10303-45 Development Team, ISO 10303-47 Development Team, ISO 10303-49 Development Team, ISO 10303-104 Development Team, ISO 10303-208 Development Team, ISO 10303-209 Development Team, ISO 10303-213 Development Team, ISO 10303-214 Development Team, ISO 10303-222 Development Team, ISO 10303-224 Development Team, ISO 10303-232 Development Team, PDES, Inc. STIR Program, PDES, Inc. and Air Force ManTech AWS Program, ANSI Y14 Committee, CALS Office - MIL-STD-2549 Project, MIL-STD-1840C, Next generation MIL-STD-1840 Program, PDES, Inc. PDM Backbone Project, PDES, Inc. Vendor's Round Table, Vendor Implementations, MSC PATRAN, ISS InSync

5 INDUSTRY ACCEPTANCE AND UTILIZATION OF PAS-C TECHNOLOGY

This section is a summary of the industrial review, acceptance, and utilization of the technology that the PAS-C Program developed.

5.1 Composite Industry Impact

The PAS-C Program had the largest impact on the composite industry in the area of general data exchange. The composites industry, like many other industries, utilizes the tools that are available for the task at hand. If a tool is not available, then the individual will create a work around to get the job completed or in the case of data exchange, to get the data from one application to another. The PAS-C Program defined a set of standards that the software tool application developers for the composite industry could utilize to transfer data between and among different computer applications with minimal user interaction and/or effort.

Much of the effort of PAS-C was in defining the general capabilities for data exchange. The composites portion of the effort was an add-on to the basic capabilities that were required for general data exchange (e.g., geometry exchange, configuration data exchange, etc).

5.1.1 Composites Terminology

One of the goals of the PAS-C Program was to standardize composite terminology within the composites industry. This goal was met with the use of the PAS-C defined terminology within the PAS-C developed APs. The industrial companies that participated in the development utilized the terminology while developing the standard, but typically fell back into the use of the respective companies jargon when returning to the home company. When the respective AP was being utilized, the terminology defined in the AP was utilized for discussion and review.

The terminology that was documented in the *Functional Needs Report for the PAS-C Program* (PASC002.01.00) was utilized in the discussions with the MIL-HDBK-17 (Composite Materials Handbook) Committee personnel related to composites terminology. The terminology was documented in a manner that was beneficial for communication of the concepts and types of composite parts that were under discussion. Although the terminology was utilized in the discussion of composite data requirements among the industrial participants, MIL-HDBK-17 personnel, IPO, the ISO, and the PAS-C team for development of the Application Reference Models (ARMs) and the review of the ARMs, the terminology was not formally adopted by the MIL-HDBK-17 Committee. MIL-HDBK-17 will be referencing AP 209 as a standard for data exchange of composites data when it becomes an International Standard.

5.1.2 National and International Standards

The PAS-C Program was directly responsible for the initiation of five international standards. The five standards are ISO 10303-49 (Integrated Generic Resources: Process Structure and Properties), ISO 10303-104 (Integrated Application Resources: Finite Element Analysis), ISO 10303-209 (Application Protocol: Composite and Metallic Structural Analysis and Related Design), ISO 10303-222 (Application Protocol: Design Engineering to Manufacturing Engineering for Composite Structures), ISO 10303-232 (Application Protocol: Technical Data Packaging Core Information and Exchange). It is expected that when the five international standards complete the ISO process for standardization that they will also be accepted as US standards. As of the date of this report the status of the standards is as follows:

- ISO 10303-49 had passed the DIS ballot and was being prepared for Final Draft International Standard (FDIS) ballot. FDIS ballot scheduled for first quarter 1997,
- ISO 10303-104 had passed the CD ballot and was being prepared for DIS ballot,
- ISO 10303-209 had passed the CD ballot and was being prepared for DIS ballot,
- ISO 10303-222 had passed the New Work Item ballot and was being prepared for Working Draft review, and
- ISO 10303-232 had passed the New Work Item ballot and was being prepared for Committee Draft ballot.

All five of the standards were fully supported by the US IPO organization prior to submission to the ISO TC184/SC4 organization for balloting as an international standard work item.

Because of the need to interoperate closely with other evolving APs, the PAS-C Team members were involved with several other STEP Parts that were in development. The ones of more significance are:

- ISO 10303-44 DAM - Draft Amendment to Integrated generic resources: Product structure configuration,
- ISO 10303-45 - Integrated generic resources: Materials,
- ISO 10303-47 - Integrated generic resource: Shape variation tolerances,
- ISO 10303-208 - Application protocol: Life cycle management - Change process,
- ISO 10303-213 - Application protocol: Numerical control process plans for machined parts,
- ISO 10303-214 -Application protocol: Core data for automotive design processes,
- ISO 10303-216 - Application protocol: Ship moulded forms, and
- ISO 10303-224 - Application protocol: Mechanical product definition for process plans using mechanical feature.

The PAS-C Team was also involved in many other related activities that enabled the development of the Application Protocols. Some of the more significant activities are:

- *Supplemental Directives for the Drafting of ISO 10303* - The PAS-C Team members were involved in this development because the PAS-C approach to getting the documentation of the standard correct the first time required the Team members to define the required sections and the required phrasing for the clear definition of the requirements for the PAS-C developed ISO 10303 (STEP) standards.
- AP Interoperability Team - The PAS-C Team members were involved in the development of guidelines of AP interoperability and the identification of the areas of overlap between different APs where adjustments could be made to allow for different APs to exchange the same data using the same data structures. Thus enabling reusable pieces of software between APs.
- *Measures Team* - A PAS-C Team member led the Measures Team that resolved the issue of how measures were to be defined in the STEP standard.
- *SEDS Team* - A PAS-C Team member is the Team leader for the draft amendment to ISO 10303-41.

5.1.3 Industry and Government Data Exchange

The PAS-C Team met with representatives of several DoD Programs to discuss utilization of the PAS-C developed standards within the respective programs for data exchange. The DoD Programs were enthusiastic about the use of the PAS-C developed APs for data submission on contracts, but were interested in the availability of the APs as COTS product add-on or a COTS data viewer/checker. Due to tight DOD budgets, the DoD Programs that were contacted could not rationalize a limited implementation of some of the AP aspects. A broad implementation of an AP at this time was not feasible because the APs had not passed the final ballot for 'International Standard' status. At the point in time when a PAS-C AP becomes an IS, the DoD Programs should evaluate the application of the AP as a contract deliverable for digital data.

To show some of the interest of utilization of the technology within industry and government, the following programs were leveraged in the development of the PAS-C APs (the status of the effort is shown in parenthesis):

- PDES, Inc.
  - Interoperability Team (on-going)
  - Vendor's Round Table (on-going)
  - FEA Pilot
    - Phase I (complete)
    - Phase II (initiated)
    - STEP TDP Interoperability and Readiness (STIR) Program (on-going)

- MADE IPD Program (in-work)
  - Lockheed Martin Tactical Aircraft Systems
    - -- Virtual Development Environment (on-going)
    - -- PDES STEP Implementation (PSI) (on-going)
- TACOM (complete)
- NIST CALS TDP Program
- MIL-STD-1840C/MIL-STD-1840 Next Generation
- AWS Program (Joint PDES, Inc. & ManTech) (complete)
- Military Products Using Best Commercial/Military Practices (MP-C/MP) (in-work)
- Digital Interface from Boeing to Northrop Grumman for commercial aircraft orders (in-work).

5.1.4 Vendor Implementations

The vendor implementations of the PAS-C developed APs were categorized into three broad categories. The first category is for Commercial-Off-The-Shelf products that are being developed for sale to a broad sector of industry. The second category is for Commercial-Off-The-Shelf products that are in the planning stages and vendors have not made a firm commitment to development of software for the product. The third category is for software products that are being developed or are in use at the respective PAS-C Team members location or being developed by organizations for internal usage.

Current or In-work COTS Products:

- MacNeal Schwendler Corporation -- PATRAN/NASTRAN,
- Integrated Support Systems, Inc. -- InSync,
- International TechneGroup, Inc. -- Composites/FEA Visualizer,
- ComputerVision -- Stresslab,
- Intergraph -- FEA Pre/Postprocessor.

Planned COTS Products:

- STEP Tools, Inc. -- Composites FEA Visualizer
- Dassault CATIA -- Composites, Shape, FEA, Materials

PAS-C Team/Organization Implementations:

- Multi-Program Release System (LMTAS),
- Metaphase (Northrop Grumman),
- NASA Lewis - Internal Systems.

5.2 Suite Utilization within Industry/Government

The suite of application protocols that were developed within the PAS-C Program have to be completed before the entire suite can be utilized within industry and government. The design of the suite was such that the different pieces of each of the application protocols could be used by the other PAS-C application protocols. Usage of AP 203, current International Standard, was used as the basis for geometric definition and configuration identification for all of the PAS-C developed application protocols. One of the salient concepts that the PAS-C Team pressed during the development of the APs was the concept of usability and interoperability of the entire STEP standard and not just the PAS-C developed APs. That is the reason that the PAS-C Team members were involved in a range of efforts from the *Supplemental Directives* development to the *Measures Team*. Due to the current development status of the respective PAS-C initiated standards, it is not reasonable to assume that industry and government would have production level implementations at this time. When the respective Application Protocols reach international standard (IS) status, it is expected that the application protocols will be used throughout industry and government. The initial COTS products that are in-work or available in the previous section are evidence that this will happen (COTS vendors do not invest unless they are convinced that there is a market for the software and that it will be profitable) when the standard becomes IS.

The application software vendor community has realized that information integration enables a smaller set of software modules to support users of the respective application software. When the smaller set of software is deployed for a single application, the vendor is able to develop and support a broader set of software modules/applications for the user. The vendors are realizing that a standards-based approach minimizes investment in information integration and reduces dependence on proprietary data formats. This increased flexibility to add or remove tools as technology evolves allows the software vendor to remain on the leading edge.

Industry and government users are primarily interested in retaining the investment in the data that was developed and produced from the application software vendor. In many cases the user's data is needed several years later (sometime decades later) and the data has to be available for use in the then current applications. If the data is in a proprietary format, the data may not be accessible to the user if the vendor has gone out of business, sold, or no longer supports the respective application. Industry and government users prefer to be able to have the data available in a non-proprietary format (preferably in a neutral standards based format) so that these issues are not insurmountable.

The availability of the data in a neutral standards based format also allows the user community another benefit that the vendor community views as not necessarily positive. A neutral standards based format allows the user community to switch software applications in and out as the requirements change or as a better product arrives on the market and is available for use.

The following sub-sections discuss the use of the respective PAS-C developed Application Protocols within industry and government.

5.2.1 Design to Analysis Application Protocol - AP 209

The software vendors that have interests in Product Data have embraced the utilization of AP 203. Many vendors have implementations of AP 203 for specific data scopes. However, engineering analysis software vendors need additional information not included in AP 203's scope to exchange the Finite Element, Computational Fluids, Kinematics, and other information between applications. Because of this requirement, many of the engineering analysis software vendors have participated in the development of AP 209 for their needs of data exchange. These vendors see AP 209 as the foundation for the development of other engineering analysis areas that are not directly covered in AP 209. The preponderance of implementations and pilots that are documented in Section 3.2 and in Section 5.1.3 illustrate that the vendor community has an interest in deploying AP 209 when it becomes an IS. The larger scope demonstrations and implementations that are documented in Section 3.2 illustrate that the industry and government representatives are also utilizing AP 209 as a basis for the larger engineering analysis set of requirements.

5.2.2 Design to Manufacturing Application Protocol - AP 222

AP 222 is in the early stages of the standards process and therefore has not had much industry or government review. AP 222 extends AP 203 into additional manufacturing areas. Specifically, tolerance information, process information, reference document information (e.g., specifications, and standards), materials, surface conditions (e.g., surface finish, surface treatment), and tooling related to engineering definition are in the scope of AP 222.

The software application vendors have the same interest in AP 222 that they have in AP 209, but for manufacturing extensions to AP 203. Another reason that software application vendors, industry, and government have an interest in AP 222 is that AP 222 furthers the 'drawingless engineering design representation' for manufacturing. AP 203 initiated this concept, but AP 203 is not complete enough for use by manufacturing; therefore, the need for AP 222.

5.2.3 Design to Support Application Protocol - AP 232

AP 232 has been through several industry and government reviews within the IPO, ISO, PAS-C Industry Review Board, DoD, Air Force, Navy, Army, and application expert reviews. The requirements definition and review are probably the most extensive for any AP at this stage of development within the ISO standards process. The PAS-C Team wanted to ensure that the AP was sufficiently complete to make it through the ISO standards process within the required schedule. The completed reviews (and resulting changes) were a key part of the strategy to get the AP through the standards process.

AP 232 is on the leading edge of a paradigm change related to how industry and government are doing business. Computing technology is becoming low cost enough that small businesses are installing advanced CAX applications as part of the normal process of doing business. With this development of infrastructure, the general industry is able to move into a digital frame of reference

and is requesting the data from the prime contractors in a format that is compatible with their respective COTS application. This has many implications:

- Companies that manage their data in a document based approach are moving to a data management approach that is digital file based. Thus, this issue is becoming a broader issue (instead of an issue only for bigger business - where big business can develop internal applications to overcome the issue). AP 232 was designed to address both methods of doing business and allow a migration path to the newer methods.
- Industry is now able to move to a capability to manage the product definition (i.e., digital files containing the product data) directly versus managing the documentation about the product definition (i.e., drawings). AP 232 is poised as an industry solution to sharing the data between the respective companies and in a format that will allow industry to migrate from the classic methods of data management to the newer methods of managing the product data directly. The software applications that are facilitating this migration are the PDM systems.
- Shipping digital files in lieu of hardcopy requires that the classic shipping list be replaced with a digital equivalent for the digital files. In the classic hardcopy arena, the sending and receiving systems were human based. AP 232 provides the capability for computer interpretatable "shipping lists".
- Newer designs are more complex and require more information and more complex information to represent the product definition. AP 232 enables the required relationships to be made.

Big business has been deploying COTS PDM Systems to address these issues. A problem with this is that most of the COTS PDM systems require a significant investment in customization to represent the required information. The PDM COTS vendors do not see this as an issue for big business because of the ability to customize the PDM software for their needs. Unfortunately, this is not the case for smaller business and PDM vendors are looking for a generic data model that satisfies the data management needs of the classic and newer methods of data management. AP 232 has been evaluated by several PDM vendors and seen as a strategic way to have a ready product out of the box which does not require significant customization. Another benefit to the PDM vendors is that if the PDM vendors have a generic data model that is utilized across PDM implementations of their product, the exchange of data between implementations will be significantly easier. The PDM vendors that have evaluated AP 232 are waiting until the AP progresses within the standards process further before they make investment in software to support this generic data model.

5.3 Implementation Issues

The largest implementation issue that is facing the PAS-C developed APs is the progression of the APs through the standards process. The administrative requirements to get through the standards process and to get the Abstract Test Suite (ATS) for the respective AP are not insignificant. As an example, an ATS can be larger than the original AP for which the ATS is applicable. Most of the ATS contains 'real world' examples of what the AP is to be exchanging, but the administrative cost

to document all of the required information for the ATS is significant. When the original PAS-C Program Plan was drafted, the ATS's were not required documentation

The second largest implementation issue that is facing the PAS-C developed APs and the STEP standards as a whole is the acceptance of the standard for data exchange. This includes the slow pace at which the standard is being developed. This pace is deemed too slow for many within industry and government that need standards now to replace standards that are quickly becoming outdated as the information technology pace increases.

The third largest implementation issue is the complexity of a STEP AP. Many software application vendors that are implementing the APs experience a large learning curve to understand the STEP approach to the standards process and the intricacies of the respective AP that the software application vendor is implementing.

5.4 AP Suite Interoperation

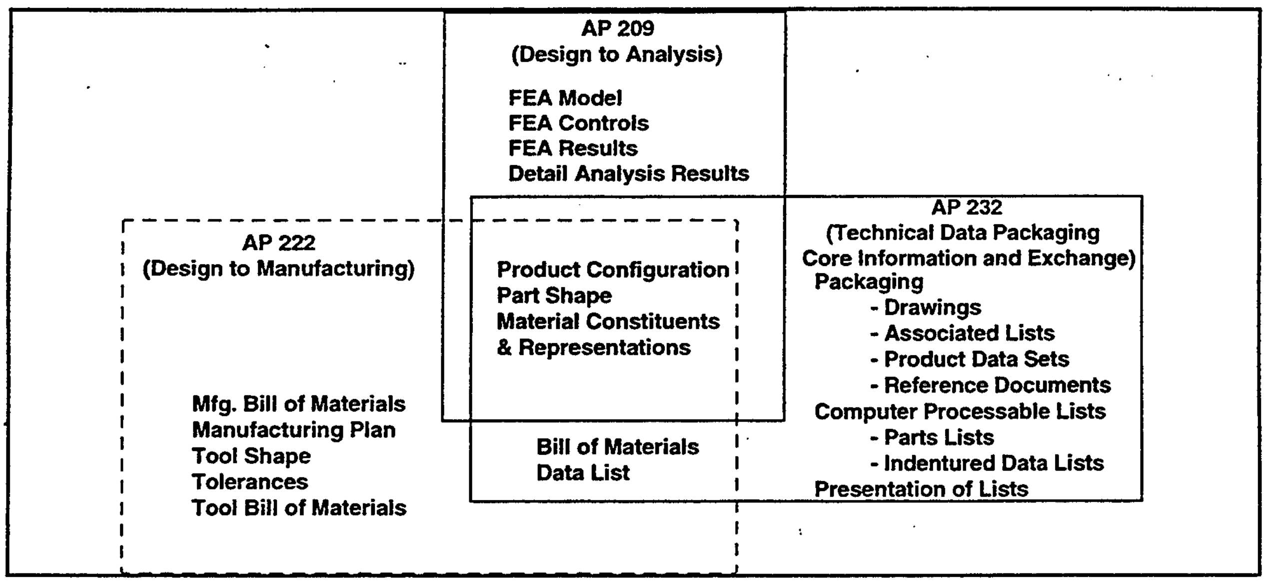

Figure 35 PAS-C AP Suite Interoperation

The APs that were developed as part of the PAS-C Program were designed with interoperability from all aspects. The APs were built upon the current STEP infrastructure that is in-place and extended the data exchange capabilities for the areas that they addressed. AP 232 was specifically designed and developed to interoperate with PAS-C developed APs and current and future AP developments. The interoperation of the APs is shown in **Figure 35**. This has basically been utilized from Program inception to define the boundaries for data sharing between the different PAS-C APs.

6 POTENTIAL FOR EXTENDING PAS-C PROGRAM EFFORTS

This section contains opportunities for extending the PAS-C results. This includes where the APs can be utilized and what additional effort needs to be expended to complete the development of the respective APs.

6.1 Web-based Technical Data Package using AP 232

The concept behind a Web-based technical data package is that the data should be available online through an affordable, secure interface leveraging Internet Web technology. Extending the current capabilities of the Web-based demonstration software for AP 232, low cost access to technical data package information could be made available independent of where the individual elements were located. This would provide for a broad based distributed storage approach that would only bring together those TDP elements that are required by a particular user (field or depot). This would also enable small manufacturing companies to have access electronically to the data they needed.

6.2 MIL-STD-1840 Replacement

A major opportunity that the Government should evaluate is the replacement of MIL-STD-1840 with the AP 232 Data Definition Exchange (DDE) capability for data exchange. MIL-STD-1840 is a military standard that should be replaced with a commercial equivalent as soon as possible. There is a great reluctance within industry to utilize this standard because it contains too many government unique requirements. AP 232 and the other parts of ISO 10303 for data exchange (e.g., physical file, SDAI) addresses the data needs for TDP data delivery and access for the government. The only areas in MIL-STD-1840 that ISO 10303 does not cover relate to business information including encryption requirements. This capability has not been exercised within any known MIL-STD-1840 data exchange.

6.3 ISO 10303-104/ISO 10303-209

ISO 103030-104 and ISO 10303-209 have passed the CD ballot and are in the process of reconciling the comments from the ballot process. To prepare for the DIS ballot, the parts will be enhanced to accommodate other capabilities that were identified as required during the CD ballot process. AP 209 also requires development of an ATS before it can be registered for a DIS ballot. Specifically, the extensions required to successfully pass the DIS ballot are:

- Substructuring so that FEA models can work together, and
- Linear and vibration mode shapes and frequencies (leverage work with AP 214).

The longer term enhancements that have been identified for ISO 10303-104 and ISO 10303-209 are:

- Non-linear FEA,
- Computational fluid dynamics - panel aerodynamics
  - Static aeroelasticity and
  - Dynamic aeroelasticity,
- Finite difference capability
  - Structured meshing and unstructured meshing.
- NURBS (varying) field representation across the surface that is associated to the mesh.
- Thermal analysis, and
- Thermal and stress analysis integration.

There are currently no electromagnetic extensions planned.

6.4 ISO 10303-222

AP 222 requires development of the AP components that are utilized by the software application vendors for implementation (e.g., AIM, conformance requirements, etc). AP 222 will also require the development of an ATS when it passes the CD ballot.

The technologies around AP 222 that are recommended for future work are in the development of the required ANSI standards for 'Drawingless Engineering Design Representation'. For the concepts of AP 222 to become a reality within industry, the respective ANSI Y14 committees need to embrace the concept and to develop the appropriate ANSI Y14 standards. ANSI Y14 is seen as the major force behind the US efforts for engineering data standardization. Within the context of ISO, ISO generally follows the ANSI Y14 recommendations and modifies the standards for international usage (e.g., metric in lieu of English units).

6.5 ISO 10303-232

AP 232 is ready for CD ballot. After the CD ballot, AP 232 will require work in reconciling the comments from the international ballot process. This is seen as requiring some technical effort, but a fairly substantial labor intensive effort because of the documentation requirements and signatures that are required to advance the documentation through the process.

Changes to ISO 10303-41 will be required to advance AP 232 through the process. This has been initiated, but will require additional effort to get the appropriate changes into ISO 10303-41 to accommodate the concepts that are required for STEP to be able to handle documents well. The original release of ISO 10303 focused on the requirements of AP 201 and AP 203 for the integrated resources. These integrated resource requirements need to be expanded to accommodate the broader set of data requirements that are being developed in AP 232 and other AP's today.

AP 232 will also require development of an ATS after it passes the CD ballot and before it can be registered as a DIS ballot.

Coordination may be required between other ISO efforts to accommodate the exchange of product definition data and the aspects of product data that are utilized by business and government to do business. AP 232 was designed to minimize the business aspects of the data, but some of this coordination may be required because AP 232 is a vehicle for data exchange that goes beyond the geometric and minimal configuration information that is contained within the current international standards. ODETTE is a European standard for the exchange of engineering drawings and some related business data. AP 232 data elements encompass all of ODETTE except a few business pieces of information that are related to the authentication of the data. This information would be part of the business processes related to the use of AP 232. AP 232 was developed to minimize the business processes contained within the AP. AP 232 use with EDI/EDIFACT would encompass the business related data within the ODETTE standard.

This page intentionally left blank.

7 SUMMARY

Significant accomplishments of the PAS-C program include:

- Established clear and comprehensive composite part information requirements
- Ensured these part information needs can be satisfied using STEP
- Identified and prioritized potential benefits from utilizing this part information in a standard information exchange environment
- Developed an ISO application protocol for Composite and Metallic Structural Analysis and Related Design (AP 209)
- Demonstrated the capabilities of AP 209 as part of other program initiatives
- Developed a draft version of an ISO application protocol for Technical Data Packaging Core Information and Exchange (AP 232) which satisfies both commercial and DoD requirements for submission to the ISO for qualification as a Committee Draft document
- Identified and documented requirements for an application protocol for the Exchange of Product Definition Data from Design Engineering to Manufacturing Engineering for Composite Structures (AP 222)
- Generated test criteria that will aid in validating implementation of the Application Protocols
- Developed demonstration software
- Conducted and supported pilots and demonstrations of AP 209 and AP 232 that will lead to near term implementations

The PAS-C Program results can be summarized as follows:

- AP 209 benefits were validated that exceeded initial projections,
- AP 222 potential benefits were projected,
- AP 232 benefit opportunities were identified and initial proof of concept was validated,
- PDES, Inc. is extending PAS-C efforts on AP 209 and AP 232,
- Commercial products are available and in-development, and
- Industry is interested in implementing PAS-C APs.

The costs for the development of this technology are fairly high, but the benefits to industry and government are even greater. PAS-C Program efforts have been a focused effort to make the STEP standard usable within the business place and not end up as an academic exercise. The PAS-C Team has brought individuals to the STEP standard process that have been instrumental in the success of the implementation of the standard.

The completion of the standards that the PAS-C Team has initiated are vital to the success of the STEP standard as a whole. The PAS-C Team did a thorough analysis of the requirements for aerospace that are applicable to other industrial sectors. The PAS-C APs are not peculiar to any single industrial sector or discipline and are of the nature and scope that they be used broadly by industry. Many of the STEP APs that are currently in development are point solutions to specific industrial sectors that will be difficult for COTS vendors to justify in an implementation. The PAS-C efforts need to be completed to the international standard (IS) level to provide industry with a usable set of standards that COTS vendors can implement for a broad range of industrial applications.

The STEP standard is a revolutionary effort that is advancing the capability of CAX Systems to integrate across applications and across platforms. This includes such aspects as geometric information of a component being related to the analysis of the component when the digital data is in different systems that is being used by different users. With the advances in PDM technologies and the STEP standard, industry will have the capability for a single product data model.

REFERENCES

1. Functional Needs Report for the PAS-C Program, Document No. PASC002.01.00, 30 September, 1991.

2. PAS-C Sample Part Set, Document No. PASC003.01.00, 30 September,1991.

3. Functional Needs IDEF0 Activity and Information Models for the PAS-C Program, Document No. PASC006.01.00, 9 January 1992.

4. PDES State-of-the-Art Assessment for the PAS-C Program, Document No. PASC005.01.00, 23 December, 1992.

5. Scoping and Benefits Criteria (Volume I - Executive Summary and Overview) for the PAS-C Program, Document No. PASC007.01.00, 14 May, 1992

6. Scoping and Benefits Criteria (Volume II) for the PAS-C Program, Document No. PASC008.01.00, 14 May, 1992.

7. Guidelines for the Development and Approval of STEP Application Protocols, Version 1.0, ISO TC184/SC4/WG4 N34 (P5), 20 February, 1992

8. EXPRESS Language Reference Manual, ISO TC184/SC4/WG5, Document No. N14, 29 April 1991.

9. Issues and Recommendations for a STEP Application Protocol Framework, NISTIR 4755, 17 January 1992.

10. Development and Demonstration Plan for the PAS-C Program, Document No. PASC010.01.00, 28 May, 1992.

11. Demonstration Plan for the PAS-C Program, Document No. PASC023.01.00, 16 October 1996.

12. Implementation of STEP for Composite Automotive Components, April 4, 1996, Industrial Technology Institute, Ann Arbor, MI.

13. Demonstration Results for the PAS-C Program, Document No. PASC027.01.00, 30 January 1997

14. MP - C/MP INITIATIVE VERIFICATION PLAN for Application Protocol 203, Initiative MI 13, MP-C/MP Program Objectives, McDonnell Douglas, St. Louis, MO.

15. Spare Parts Production and Reprocurement Support Systems; State of the Art Survey & Cost Benefit Analysis, Vol 1, State of the Art Survey, General Atomics GA-C20701; AFWAL Contract Number F33615-90-C-5002, September 1991.

16. State of the Art Survey & Cost benefit/Risk Analysis (CDRL A016), Addendum to Volume I: State of the Art Survey, General Atomics GA-C20701; AFWAL Contract Number F33615-90-C-5002, December 1992.

17. State of the Art Survey & Cost/Benefit/Risk Analysis (CDRL A016), Volume II: Cost/Benefit/Risk Analysis, General Atomics GA-C270701; AFWAL Contract Number F33615-90-C-5002, December 1992.

18. Cost Analysis Model Based on Savings Resulting from the Reduction of Procurement Cycle Time for Recoverable Landing Gear Item Achieved Through the Implementation of the Spares System, White Paper, OO-ALC/TIERS, Hill Air Force Base, UT 84056-5805.

19. Building Blocks for the Technical Data Package Application Protocol, Document No. PASC013.01.00, 27 September 1994.

Appendix A - PAS-C Related Documents

Program Master Plan for the PAS-C Program, Document No. PMG001.01.00, 30 August 1991

Functional Needs Report for the PAS-C Program, Document No. PASC002.01.00, 30 September 1991

PAS-C Sample Part Set, Document No. PASC003.01.00, 30 September 1991

1991 Annual Report for the PAS-C Program, Document No. PASC004.01.00, 30 September 1991

PDES State-of-the-Art (SOTA) Assessment for the PAS-C Program, Document No. PASC005.01.00, 23 December 1991

Functional Needs IDEF0 Activity and Information Models for the PAS-C Program, Document No. PASC006.01.00, 9 January 1992

Scoping and Benefits Criteria (Volume I - Executive Summary and Overview) for the PAS-C Program, Document No. PASC007.01.00, 14 May 1992

Scoping and Benefits Criteria (Volume II) for the PAS-C Program, Document No. PASC008.01.00, 14 May 1992

Functional Needs/State-of-the-Art Comparison for the PAS-C Program, Document No. PASC009.01.00, 28 May 1992

Development and Demonstration Plan for the PAS-C Program, Document No. PASC010.01.00, 28 May 1992

1992 Annual Report for the PAS-C Program, Document No. PASC004.02.00, 30 September 1992

Program Master Plan for the PAS-C Program, Document No. PMG001.02.00, 15 October 1992

Program Master Plan for the PAS-C Program, Document No. PMG001.03.00, 12 July 1993

Application Reference Model for Application Protocol 209 (AP 209) - Design through Analysis of Composite and Metallic Structures for the PAS-C Program, Document No. PASC011.01.00, 6 August, 1993, and Document No. PASC011.01.01, 10 September 1993

Information Model for Application Protocol 209 (AP 209) - Design through Analysis of Composite and Metallic Structures for the PAS-C Program, Document No. PASC012.01.00, 28 September 1993

1993 Annual Report for the PAS-C Program, Document No. PASC004.03.00, 30 September 1993

Building Blocks for the Technical Data Package Application Protocol, Document No. PASC013.01.00, 27 September 1994

Planning Model for the Technical Data Package (TDP) Application Protocol, Document No. PASC014.01.00, 27 September 1994

Requirements Document Addendum for the Technical Data Package (TDP) Application Protocol for the PAS-C Program, Document No. PASC015.01.00, 30 September 1994

Preliminary Rapid Prototyping Plan for the Technical Data Package (TDP) Project for the PAS-C Program, Document No. PASC016.01.00, 28 September 1994

Application Activity Model for the Technical Data Package (TDP) Application Protocol for the PAS-C Program, Document No. PASC017.01.00, 28 September 1994

Program Master Plan for the PAS-C Program, Document No. PMG001.04.00, 30 September 1994

1994 Annual Report for the PAS-C Program, Document No. PASC004.04.00, 30 September 1994

Test Criteria for AP 209 - Composite and Metallic Structural Analysis and Related Design for the PAS-C Program, Document No. PASC018.01.00, 7 October 1994

Initial Committee Draft version of AP 209, Document No. PASC019.01.00, 14 October 1994

Preliminary Application Reference Model for the Core Technical Data Package (TDP) Application Protocol for the PAS-C Program, Document No. PASC020.01.00, 21 December 1994

Program Master Plan for the PAS-C Program, Document No. PMG001.05.00, 30 September 1995

1995 Annual Report for the PAS-C Program, Document No. PASC004.05.00, 30 September 1995

Application Reference Model for the Technical Data Package Core Application Protocol for the PAS-C Program, Document No. PASC021.02.00, 19 October 1995

Committee Draft version of AP 209, Document No. PASC019.02.00, 1 December 1995

Updated Application Reference Model for the Technical Data Package Core Application Protocol for the PAS-C Program, Document No. PASC021.03.00, 6 December 1995

Information Model for the Technical Data Package Core Application Protocol for the PAS-C Program, Document No. PASC022.01.00, 31 January 1996

Initial Application Interpreted Model for the Technical Data Packaging Core Information and Exchange Application Protocol for the PAS-C Program, Document No. PASC024.01.00, June 1996

1996 Annual Report for the PAS-C Program, Document No. PASC004.06.00, 30 September 1996

Demonstration Plan for the PAS-C Program, Document No. PASC023.01.00, 16 October 1996

Test Criteria for AP 232 for the PAS-C Program, Document No. PASC025.01.00, 30 January 1997

Application Reference Model for AP 222 for the PAS-C Program, Document No. PASC026.01.00, 30 January 1997

Demonstration Results for the PAS-C Program, Document No. PASC027.01.00, 30 January 1997

Software Product for the PAS-C Program, Document No. PASC028.01.00, 30 January 1997

Final Technical Report and Benefits Analysis for the PAS-C Program, Document No. PASC029.01.00, 31 January 1997

This page intentionally left blank.

Appendix B - Node Decomposition for Design to Support

The following task descriptions are for node A24 decomposition, 'SUPPORT LOGISTICS OF AN AIRCRAFT COMPOSITE STRUCTURAL PART (ACSP)'. This was developed from input from experts that have operated within the ALC environment for Logistics Support. **Figure 36**, **Figure 37**, and **Figure 38** contain a simplified ICOM of the task decompositions.

TASK DESCRIPTIONS

A23 Released Engineering Design.

The TDP from engineering release is used as initial input design data to establish and complete the logistics Support Process.

A24 Support Logistics of a Product

This activity involves the Logistics Engineering, Reliability and Maintainability (R&M)Design Studies, Technical and Maintenance Manual documentation, Spares and Repair Parts Provisioning, Support Facilities and Training for personnel who operate and maintain the end item. These tasks are described in Mil- Std 1388-1A (Logistics Support Analysis ,LSA). Data generated by the LSA is stored and transferred in the Logistics Support Analysis Record (LSAR) as described in Mil-Std 1388-2B.

A241 Perform Logistics Engineering

This task includes mission and support system definitions to establish Supportability objectives and Supportability related design goals, thresholds and constraints through comparison with existing support systems. This activity accomplishes the LSA 200 level tasks and generates the Customer Use Study.

A2411 Customer Use Study

This study (LSA task 201) is to identify and document the pertinent Supportability factors related to the intended use of the end item. Factors to be considered include; mobility requirements, deployment scenarios, mission length, frequency and duration, basing concepts, anticipated service life,, operational environment and human capabilities/limitations. Both peacetime and wartime employment shall be considered in identification of Supportability factors. Data used in the development of support alternatives include; operational requirements consisting of number of missions per unit of time, number of operating days, hours firing of cycles of time.

A242 Support R & M Design Studies

These studies establish Supportability cost and readiness objectives for the end item and identify risks or uncertainties involved in achieving the established objectives. Standardization with existing end items is also considered in establishing Supportability related design constraints for inclusion in specifications, procurement contracts and other related documents. This effort completes the remaining LSA 200 tasks.

A2421 Perform Maintenance Task Analysis

This task documents the required operations and maintenance tasks for the new system/end-item to identify support resources required for each maintenance task. Included in this task is repair level analysis to establish unit and depot support plans to include test/support equipment, spares stockage and transportation requirements. This analysis provides source data for preparation of ILS documentation (technical manuals and training programs) and spare/repair parts provisioning.

A243 Write Technical Manuals

This task creates, compiles, publishes and distributes the operation, maintenance and repair technical manuals for the end item. This function is also a user of the Engineering Design files in the preparation of Illustrated Parts and Structural Repair Manuals.

A2431 Identify and Deliver Spares/Repair Parts

This task uses the LSAR data to complete the H and H1 LSAR data records which are used to transmit Provisioning Technical Documentation (PTD) to the customers support center (USAF Air Logistics Center). PTD normally consists of hard copies of engineering drawings and magnetic tapes of spare/repair part procurement data. PTD reports may be submitted in hard copy or magnetic tape for customers use to input into the USAF D-220 automated system. *This process translates the Engineering Design drawings into procurable assemblies, sub-assemblies and repair parts used by the customer for future procurement of spares and replacement parts.* LSAR data and PTD is revised and up-dated as a result of future design changes to maintain configuration identity with the end items being supported.

This task starts with the customers use study showing the number of systems, expected usage, number of operating locations, War Readiness Spares Kit requirements and initial repair concept. The Contractor team , using early R & M analysis on Failure rates, repair times and maintenance significant items (MSI) develop a recommend list of initial spares to be procured and delivered with the first end item. Manufacture of these initial spares are normally integrated with the first production articles. This process, Spares Integrated with Production (SAIP) results in a lower price for spares due to increases in unit production .

A2432 Develop Provisioning Technical Documentation

This task starts with a review of the engineering drawings to break out procurable assemblies or piece parts to be delivered as spares or repair parts. The provisioning analyst receives guidance from the customer concerning the type of maintenance/support concept , equipment operating hours, and level of spares stockage planned for the various operating and support sites. The provisioning analyst also uses reliability rates and projected failure rates to compute the recommended range and depth of spare parts needed to sustain the customers required aircraft availability rates. Results of the provision process are recorded in the LSAR "H" sheets which are used to extract reports and files for delivery to the customer.

The USAF/ALC electronic D-220 system receives the provisioning file in magnetic tape format. The electronic file is usually accompanied by two hard copies of the engineering drawings and application parts lists. The ALC receivers and stores this data for future use to repair or reproduce needed spares and repair parts. *Maintaining storage and retrieval of this provisioning data is the most labor intensive segment of the spares reprocurement process. Use of the PAS-C standard for the electronic transfer of the engineering TDP would offer significant reduction in the labor costs to store/retrieve the data. More importantly, electronic retrieval should permit a large reduction in the administrative lead time needed to assemble the spares reprocurement data package needed to effect future resupply.* **A detailed description of this process is provided in reports created by *Spare Parts Production and Reprocurement Support (SPARES) System* which documented IDEF activity and information modes under GA project 3902.**

A2433 Forecast Follow-on Spares and Repair Parts

This task continues the provisioning process to identify detailed parts, repair kits and additional stockage for deport support and repair centers.

A2434 Identify Consumable and Bulk Items

This task establishes the consumable items of POL; bench-stock and other materials that are required to support flight operations. Estimated quantities and recommended sources are provide for local purchase.

A2435 Procure Replacement Spares and Repair Parts

This task provides the spares order and delivery process in response to a customer order. A Provisioning Item Order (PIO) is the USAF term for a quotation of price and delivery of a requested quantity of items. The contractors acknowledgment of the order confirms the terms and conditions of the order and becomes a contract for delivery at a scheduled future date. This is a routine process as long as the requested items are still in production, out of production spares orders often require extended negotiations concerning tool and set up time/costs to produce small quantities. This task provides continuing interface with the ALC for the processing of spares orders. ***Both contractor and USAF continue to use the LSAR,***

Provisioning data records and revised engineering drawings to maintain correct configuration between spares orders and the end items being supported.

A245 Support Facilities

This task identifies required support facilities.

A246 Training Documentation

This task creates and conducts required training the operation and maintenance of the end item.

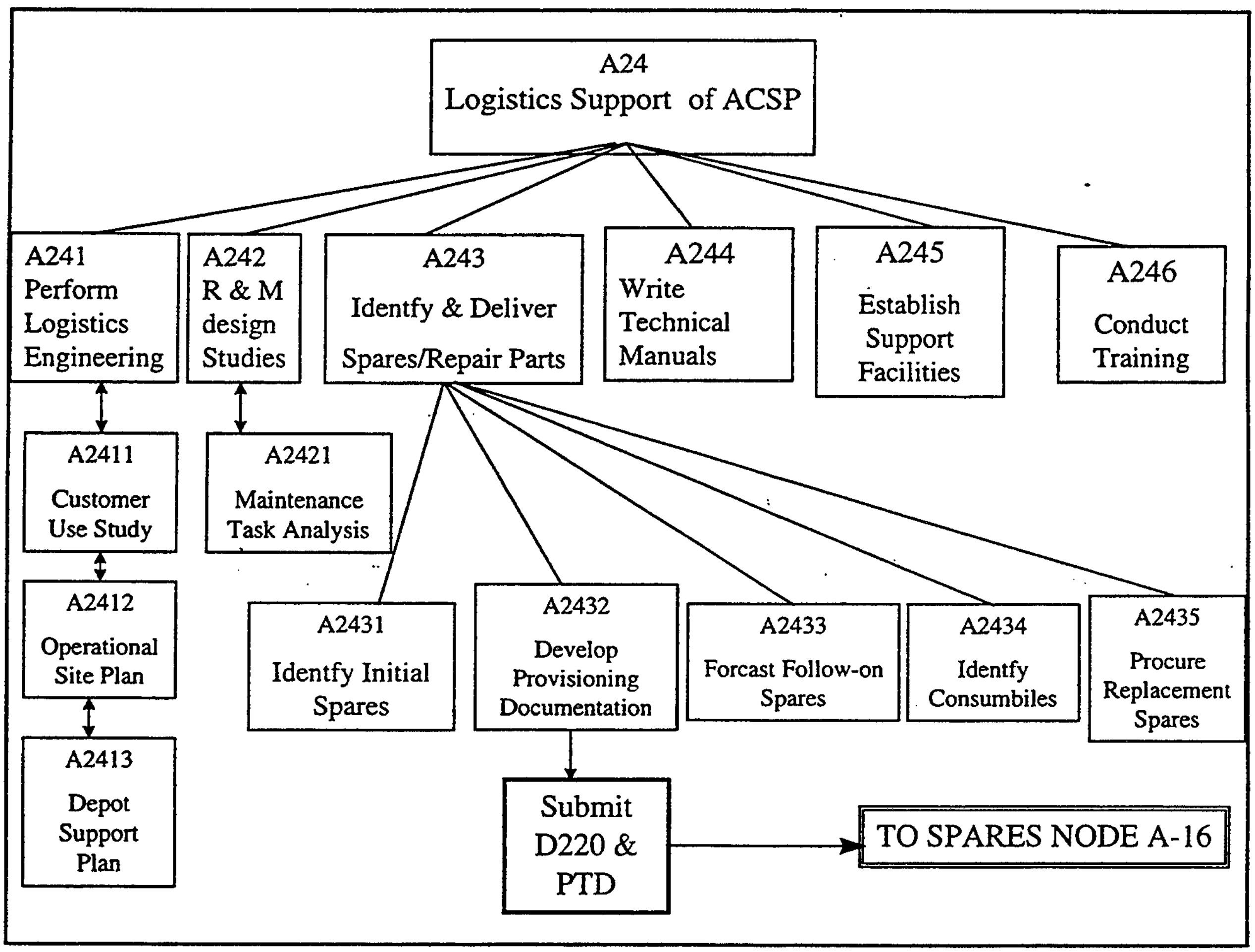

Figure 36 Simplified LSAR Diagram

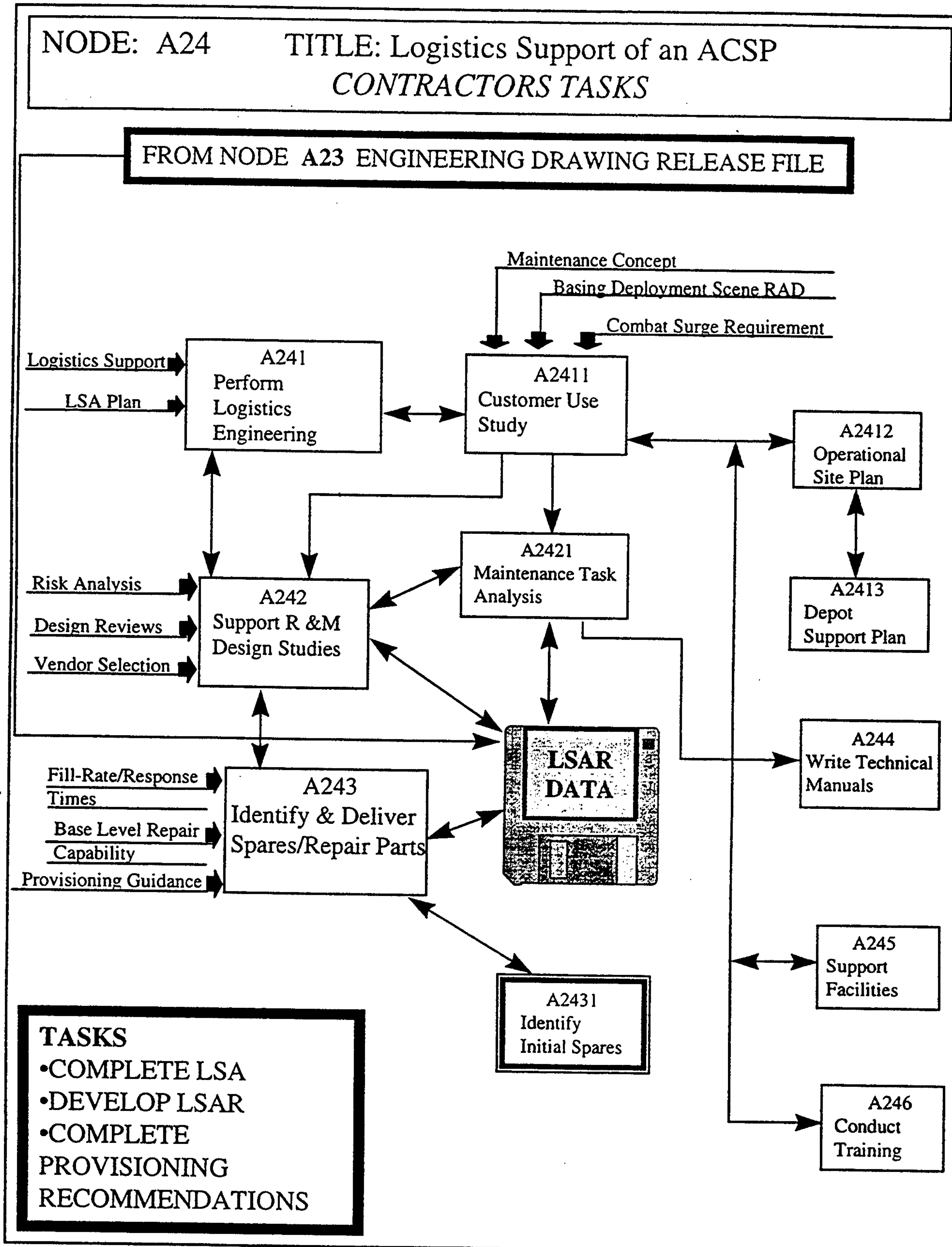

Figure 37 Node A24

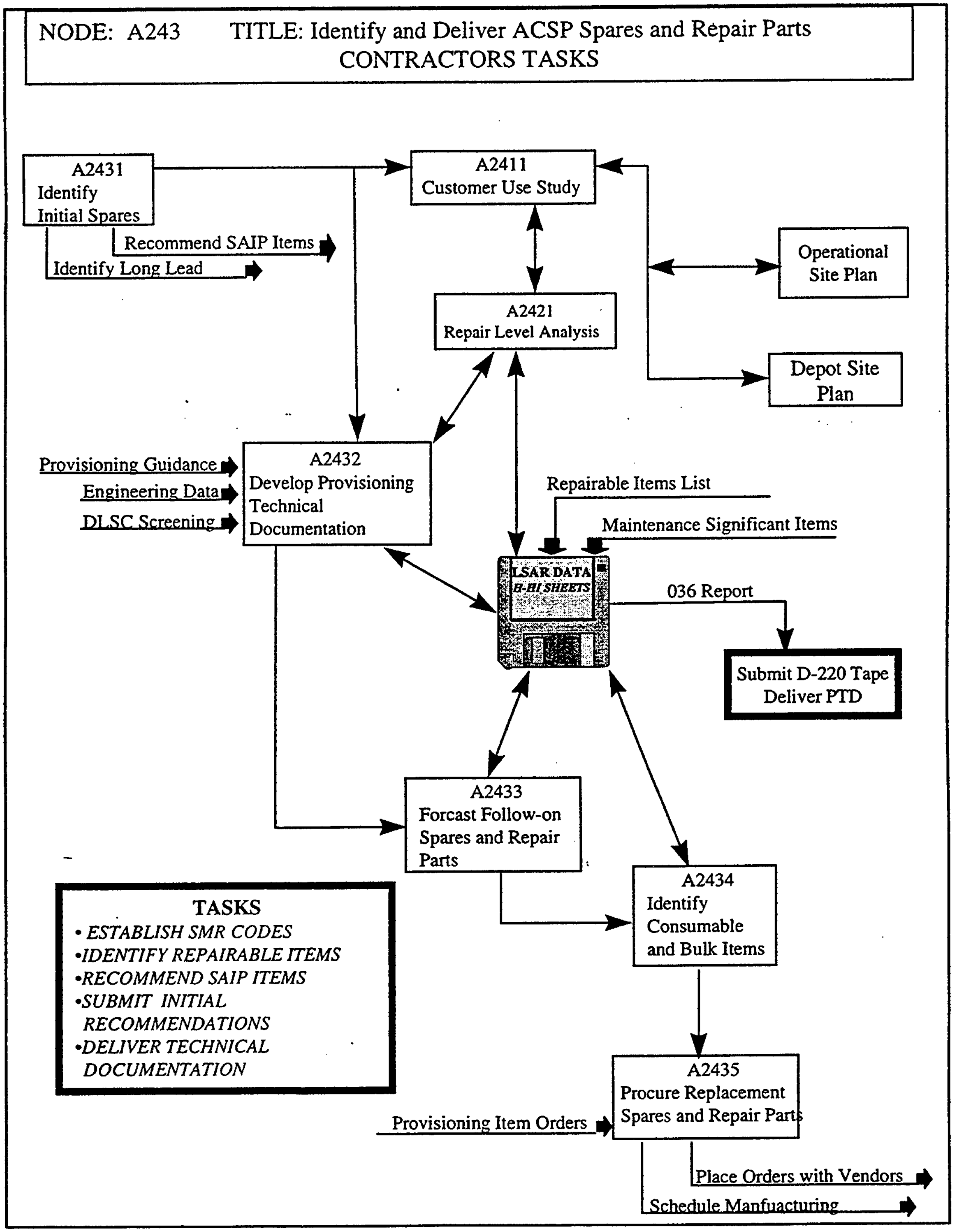

Figure 38 Node A243